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IMPROVED SEAT, CONSOLE, AND WORKPLACE DESIGN

Annotated Bibliography, Integration of the Literature, Accommodation Model, and Seated Operator Reach Profiles

(AIRTASK A62763N/WF55.525.403)

Compiled by

M. M. AYOUB and C. G. HALCOMB
Texas Tech University

(Contract N61756-75-M-2986)

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PACIFIC MISSILE TEST CENTER

Point Mugu, California

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PACIFIC MISSILE TEST CENTER

AN ACTIVITY OF THE NAVAL AIR SYSTEMS COMMAND

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This report was prepared with the objective of integrating pertinent information regarding seat, console, and workplace design. Each of the four sections is coauthored by research associates working under the direction of the principal investigators. The four sections include:

Section A. An annotated bibliography about seating, console, and workplace designs. Each relevant publication is summarized to reflect a category, author, title, methodology, rationale, significant results, conclusions, and recommendations.

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20. ABSTRACT *(Concluded)*

Section B. Integration of the seat, console, and workplace design. The detailed aspects of these components and their relationship to each other in making up the workplace are discussed. The basic recommendations about the seat, the console, and the workspace needed for the operator are discussed.

Section C. A workplace-accommodated percentage evaluation model. A model and preliminary results are presented to show the percentage excluded from a seat/console design, given the percentage excluded based on individual dimensions. Cutoff percentage points are established to ensure accommodation of approximately 90 percent of the potential user population.

Section D. Reach profiles for restrained and unrestrained males and females. Reach envelope data and new methodologies for collecting data are presented, and are compared with existing reach data.

ACKNOWLEDGMENT

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(AIRTASK A62763N/WF55.525.403)

Prepared by
Texas Tech University
Lubbock, Texas 79409

SUMMARY

This report was prepared with the objective of integrating pertinent information regarding seat, console, and workplace design. Each of the four sections is coauthored by research associates working under the direction of the principal investigators. The four sections include:

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SECTION A

SECTION A

SEATING, CONSOLE, AND WORKPLACE DESIGN:
An Annotated Bibliography

By

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CONTENTS

SUMMARY

Section A is a bibliography, in an easily used format, of key anthropometric characteristics involved in the design and evaluation of seats, consoles, and workplaces. It satisfies the urgent need to integrate and update the literature.

Ninety-seven publications were read. Each publication was categorized into six divisions: (1) anthropometry, (2) seat design, (3) console design, (4) workplace design, (5) reach envelope, and (6) models.

Salient information from the 97 publications is summarized in table A-1.

INTRODUCTION

The areas of seating, console, and workplace design draw upon a number of diverse fields. These fields include human factors/ergonomics, physical anthropology and many others. Because of this, the literature on workplace design, as with any multi-disciplinary field, is scattered and frequently unintegrated. Prior to this report, there have been few comprehensive and integrated efforts at collecting and structuring the seating, console, and workplace design literature in a usable format. An information file on the principles involved in console and seat design is required since more engineers and designers are called upon to apply such information in the design and redesign of both new and old systems. At this time, many of the references being used for such purposes are, at best, out of date and do not take advantage of new methods of data collection and analysis which have come into being since their publication. Therefore, there is an urgent need for an annotated bibliography on seat, console, and workplace design which integrates and updates the literature in the area. The purpose of this bibliography is to provide an overview of key anthropometric characteristics involved in the design and evaluation of seats, console, and workplaces in an easily used format.

METHOD

The basic approach taken in the initial phase of the literature search was two-fold. First, key publications by well-known authors in the field of anthropometry were abstracted and scanned for other salient references. These publications included reviews by Ayoub (1971), Kroemer (1971), Murrell (1965), Roebuck, Kroemer, and Thomson (1975), and Hertzberg (1974). Second, a computerized literature search utilizing two major data bases (i.e., National Technical Information Service NTIS and Compendex) was performed. After references were located they were categorized as follows: (1) Anthropometry,

(2) Seat Design, (3) Console Design, (4) Workplace Design, (5) Reach Envelope, and (6) Models. Table A-1 includes a summary of the publications, which were annotated into the six previously described categories. This table is provided as a guide to the bibliography. Abstracts of relevant information were performed and included (1) Author, Title, and Citation, (2) Rationale, (3) Methodology, including sample size, population characteristics, clothing, man/hardware relationship, procedures, apparatus, and other aspects of method, (4) Significant Results, (5) Conclusions/Recommendations, (6) Supplementary References, and (7) Comments.

The abstracting consisted of reading the article in its entirety, choosing salient information from the text and tables, and then summarizing the information sometimes employing the author's own words.

DISCUSSION

The above-mentioned reviews provided the greatest number of relevant references (approximately 90%) but the computerized literature search did provide both (1) good coverage in disjoint areas and (2) a check to ensure that no oversights had been made. The computerized literature search yielded approximately a unique 10 per cent of the references abstracted. The most fruitful approach in searching this area of research appears to be scanning key references and working backwards from the reference sections of these articles until duplication begins.

The results of this search are given in the annotated bibliography. An integration, relative to workplace design, is found in Dannhaus and Bittner (1976). This integration, in turn, was the basis of the Bittner, Dannhaus, and Roth (1976) paper utilizing a Monte Carlo model approach to the accommodated percentage excluded on a console/workplace design. Both papers used the present annotated bibliography as an information base and background source for their discussions.

Table A-1. Summary of Surveyed Articles

Reference	Anthropometry	Seat Design	Console Design	Workplace Design	Reach Envelope	Models
Akerblom, B. (1954)		X				
Ayoub, M. M. (1971)		X		X		
Ayoub, M. M. (1973)				X		
Barkla, D. (1961)	X	X				
Bittner, Jr., A. C. (1974)				X		X
Bittner, Jr., A. C. & Moroney, W. F. (1974)				X		
Branton, P. & Grayson, G. (1967)		X				
Bullock, M. I. (1973)			X		X	
Bullock, M. I. (1974)					X	
Burandt, U. & Grandjean, E. (1963)		X				
Chaffin, D. B., Schutz, R. K., & Snyder, R. G. (19)					X	X
Chidsey, K. D. & Shackel, B. (1966)		X				
Chidsey, K. D., Shackel, B., & Shipley, P. (1966)		X				
Churchill, E., McConville, J. T., Laubach, L. L., & White, R. M.	X					
Croney, J. (1971)	X	X		X		
Damon, A. & Randall, F. E. (1944)	X					
Damon, A., Stoudt, H. W., & McFarland, R. A. (1966)	X	X				
Daniels, G. S. (1952)	X					

TABLE 1 (Cont.)

Reference	Anthropometry	Seat Design	Console Design	Workplace Design	Reach Envelope	Models
Darcus, H. D. & Weddell, A. G. M. (1947)		X				
Dempster, W. T. (1955)	X					
Dempster, W. T., Gabel, W. C., & Felts, W. J. L. (1959)					X	
Duncan, J. & Ferguson, D. (1974)				X		
Ellis, D. S. (1951)				X		
Ely, J. H., Thomson, R. M., & Orlansky, J. (1956)					X	
Ferguson, D. & Duncan, J. (1974)				X		
Floyd, W. F. & Roberts, D. F. (1958)		X				
Floyd, W. F. & Ward, J. S. (1967)				X		
Floyd, W. F. & Ward, J. S. (1969)		X				
Garner, J. (1936)		X				
Gifford, E. C., Provost, J. R., & Lazo, J. (1964)	X					
Grandjean, E., Hunting, W., Wotzka, G., & Scharer, R. (1973)		X				
Hawkins, F. (1974)		X				
Hertzberg, H. T. E. (1955)	X					
Hertzberg, H. T. E. (1960)				X		
Hertzberg, H. T. E., Daniels, G. S., & Churchill, E. (1954)	X					
Hooton, E. A. (1945)	X	X				

TABLE 1 (Cont.)

Reference	Anthropometry	Seat Design	Console Design	Workplace Design	Reach Envelope	Models
Jones, J. C. (1966)		X				
Hugh-Jones, P. (1947)					X	
Jones, J. C. (1969)		X				
Karvonen, M. J., Koskela, A., & Noro, L. (1962)		X				
Keegan, J. J. (1953)		X				
Keegan, J. J. (1962)		X				
Kennedy, K. W. (1964)					X	
Kennedy, K. W. & Bates, Jr., C. (1965)			X			
Kilpatrick, K. E. (1972)				X		X
Kirk, N. S., Wards, J. S., Asprey, E., Baker, E., & Peacock, B. (1969)		X				
Kocker, A. L. & Frey, A. (1932)		X				
Konz, S. A., Jeans, C. E., & Rathore, R. S. (1969)						X
Koskela, A. (1962)				X		
Kroemer, K. H. E. (1971)		X	X	X		
Kroemer, K. H. E., & Robinette, J. C. (1968, 1969)		X		X		
Kubokawa, C. & Woodson, W. (1969)		X	X	X		
Langdon, F. J. (1965)		X	X			

TABLE 1 (Cont.)

Reference	Anthropometry	Seat Design	Console Design	Workplace Design	Reach Envelope	Models
Laubach, L. L., & Alexander, M. (1975)				X	X	
Le Carpentier, E. F. (1969)		X				
Less, M., Eickelberg, W. W. B., & Palgi, S. (1973)				X		
Lewin, T. (1969)	X					
Lundervold, A. (1958)		X		X		
McFarland, R. A., Damon, A., & Stoudt, Jr., H. W. (1958)	X	X			X	
McFarland, R. A., Damon, A., Stoudt, H. W., Moseley, A. L., Dunlap, J. W., Hall, W. A. (1953)	X	X				
McFarland, R. A., Dunlap, J. W., Hall, W. A., & Moseley, A. L. (1953)		X		X		
Mohr, G. C., Brinkley, J. W., Kazarian, L. E., & Millard, W. W. (1969)		X				
Morant, G. M. (1947)	X					
Morgan, C. T., Cook, J. S., Chapanis, A., & Lund, M. W. (1963)		X	X	X		
Moroney, W. F. (1971)	X					
Moroney, W. F., Kennedy, R. S., Gifford, E. C., & Provost, J. R. (1971a)	X					
Moroney, W. F., Kenndey, R. S., Gifford, E. C., & Provost, J. R. (1971b)	X					
Moroney, W. F. & Smith, M. J. (1972a)	X					
Moroney, W. F. & Smith, M. J. (1972b)	X					

TABLE 1 (Cont.)

Reference	Anthropometry	Seat Design	Console Design	Workplace Design	Reach Envelope	Models
Morrison, J. F. (1965)	X	X		X		
Murrell, K. H. (1969)		X				
Nissley, H. R. (1949)		X				
Nissley, H. R. (1951)		X				
Nissley, H. R. (1952)		X				
Oshima, M., Fujimotor, T., Oguro, T., Tobimatsu, N., Mori, T., Tanaka, I., & Watanabe, T. (1965)	X					
Oxford, W. F. (1969)		X				
Rice, E. V., & Ninow, E. H. (1973)	X	X				
Ridder, C. A. (1959)		X				
Rosener, A. A. & Stephenson, M. L. (1974)		X				
Shackel, B. (1959)			X			
Shackel, B., Chidsey, K. D., & Shipley, P. (1969)		X				
Siegel, A. I., & Brown, F. R. (1958)			X			
Slechta, R. F., Wade, E. A., Carter, W. K., & Forrest, J. (1957)		X				
Stoudt, H. W. (1973)					X	
Stoudt, H. W., Damon, A., McFarland, R. A., & Roberts, J. (1965)	X					
Snyder, R. G., Chaffin, D. B., & Schutz, R. K. (1971)					X	

TABLE 1 (Cont.)

Reference	Anthropometry	Seat Design	Console Design	Workplace Design	Reach Envelope	Models
Van Cott, H. P. & Kinkade, R. G. (1972)		X	X	X		
Wachsler, R. A. & Learner, D. B. (1971)	X					
Washburn, C. T. (1932)		X				
Weddell, G. & Darcus, H. D. (1947)		X				
White, R. M. & Churchill, E. (1971)	X					
Woodson, W. E., & Conover, D. W. (1964)		X	X	X		
Wotzka, G., Grandjean, E., Burandt, U., Kretzchmar, H., & Leonhard, T. (1969)		X				
Yllo, A. (1962)				X		

CATEGORY: SEAT DESIGN

AUTHOR: Akerblom, B.

TITLE: Chairs and sitting.

CITATION: In Symposium on Human Factors in Equipment Design (Edited by W.F. Floyd and A.T. Welford) London: H.K. Lewis, p. 29-35, 1954.

RATIONALE: Reviews the design dimensions of chairs and then sets forth recommendations for different dimensions of a chair.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) The thigh is ill-adapted for supporting even its own weight on a seat, much less that of the upper part of the body. Consequently, the chair must be constructed so that the weight of the body is borne on the ischial tuberosities. The thigh should be able to hang freely or only rest gently on the seat.
(2) The height of the seat should be 40 cm.
(3) The depth of the seat should be between 45-47 cm.
(4) The slope of the seat should be 5°-7° (backwards).
(5) The chair should be designed so that there may be changes in the posture while sitting.
(6) The slope of the backrest should be about 115° for ordinary chairs.
(7) The lumbar convexity of the backrest should be 20 cm. above the seat. The lumbar support should begin at the top of the sacrum.
(8) Table height should be 68-70 cm.
(9) The distance between the seat of chair and the table top should be 30 cm.

CATEGORY: SEAT DESIGN AND WORKPLACE DESIGN

AUTHOR: Ayoub, M.M.

TITLE: Posture in industry.

CITATION: Paper presented at Human Factors Society Meeting, New York, Oct. 19-21, 1971.

RATIONALE: The paper discusses the requirements of industrial seats, the workspace for both the sitting and standing operator, and ergonomic guidelines for proper industrial posture. The recommendations and guidelines for seating, workspace, and posture are a summary of the literature in this area. The workspace design section is included in Ayoub (1973).

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Seat pan - Although in some cases the profiles of seat pans are desirable, generally, no shaping is recommended for industrial or office chairs. One of the important features of a good chair is that it permits changing posture with ease. A horizontal seat pan would cause the sitter to be ejected from the seat if he leans against the backrest. A slight rearward slope of the entire seat pan of approximately 3°-5° is preferred. This causes the sitter's trunk to tilt towards the backrest, and at the same time prevent ejection of the sitter. If the seat pan is slightly concave in the center, this concavity will help maintain the sitter in the middle of the seat, preventing sliding. The seat pan should be upholstered. On a hard seat surface, the trunk weight is transmitted through the small areas to the seat, causing high pressure points. This results in reduced blood flow leading to numbness and pain. Soft upholstery is not recommended for it makes it difficult to gain relief by adjusting the body. The upholstery should be stiff and not give way any more than 1 inch. Such upholstery would not only reduce pressure on the buttocks, but also permit change of posture. The upholstery should afford ventilation for the sitter to reduce sweating.

(2) Seat pan height - If seat height is properly adjusted, the individual's sitting posture is characterized by lower legs being vertical, the feet flat on the floor, and the thighs horizontal. The height of the seat should be slightly less than the popliteal height. The height should be approximately 18 in. above the floor, but chair height should be adjustable (16-20 in. above floor).

(3) Backrest - The backrest should be approximately 3-6 in. above the seat. This allows the pelvis to be moved back permitting support of the lumbar spine by the backrest. If the seat is to be used in operations where freedom of the shoulders and the arms is necessary, then a small backrest should be provided. The backrest should swivel to allow for a better fit between the curvature of the spine and the backrest.

Backrest dimensions - Approx. 13x7 in. slightly convex in profile

Backrest height - lower edge approx. 4 in. above the seat pan

Backrest swivel - $\pm 10°$ against vertical about a horizontal axis

Backrest in-cut - 14-17 in. from front edge of seat

(4) Footrests - A good footrest offers a large surface to place the feet. The footrest should be concave to accomodate the normal movement of the feet.

(5) Armrests - Arm rests are often desirable. Usually one armrest on one side will suffice. One armrest on one side will not interfere with getting into or out of the chair. Armrests are also used on the work bench to support the elbow. and forearms; raised or lowered out of the way when not in use.

(6) Swivel seats - A seat rotating about a pivot is often desirable when the operator has to turn to perform his task such as when L or U shaped work areas are used. Swivel chairs should be able to be locked into position.

(7) Casters - Casters on industrial seats are usually discouraged.

CATEGORY: WORKPLACE DESIGN

AUTHOR: Ayoub, M.M.

TITLE: Work place design and posture.

CITATION: Human Factors, 1973, 15, 265-268.

RATIONALE: Inefficient operation, injury, and accidents, as well as reduced output are influenced by the design of the workplace. This paper presents a brief summary of some of the critical dimensions in workplace design.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

Seated operator

Work Surface Height	Males	Females
(a) For fine work, exacting visual tasks	39.0 - 41.5 in.	35.0 - 37.5 in.
(b) For precision work, mechanical assembly work	35.0 - 37.0 in.	32.5 - 34.5 in.
(c) For writing or light assembly work	29.0 - 31.0 in.	27.5 - 29.5 in.
Typing activities	lower than previous dimensions by 2 to 3 in.	
(d) For course or medium manual work (e.g., packaging)	27.0 - 28.5 in.	26 - 27.5 in.

Work Space
(a) Width: minimum 20 in. (leg room)
(b) Depth: 25 in., if limited (leg room)
(c) Optimum work area should be approximately 100 square in., located 4 in. from edge of work surface
(d) Knee depth: minimum 12 in. (leg room)
(e) Footroom: minimum 10 in. (leg room)
(h) Work surface height: 26 in. minimum
Must have minimum room of 24 in. to clear knees.

Standing operator

Work Surface Height	Males	Females
(a) For precision work with supported elbows, the work surface should be 2 in. above elbow height	43 - 47 in.	40.5 - 44.5 in.
(b) For light assembly work, the work surface height should be 4 in. below elbow height	39 - 43 in.	34.5 - 38.5 in.
(c) For heavy work, the work surface height should be 8 in. below elbow height	33.5 - 39.5 in.	31 - 37 in.

Work Space

Sufficient room should be allowed for knees and feet (e.g., 6 in.).

Included in the paper are some general guidelines for working postures.

CATEGORY: ANTHROPOMETRY AND SEAT DESIGN

AUTHOR: Barkla, D.

TITLE: The estimation of body measurements of British population in relation to seat design.

CITATION: *Ergonomics*, 1961, 4, 123-132.

RATIONALE: It is generally agreed that the dimensions of the chair should be in reasonable agreement with the dimensions of the person sitting in it. Good fit alone may not ensure comfort, but bad fit will almost certainly ensure discomfort. Few anthropometric surveys were British or were intended to provide data for designers of seats, this paper estimated the measurements of young British adults derived from the published material.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: Estimated measurements, in inches, of the British population between 18 and 40.

	Males		Females	
	Mean	S.D.	Mean	S.D.
Stature	67.25	2.6	63.25	2.6
Sitting height	35.25	1.4	33.25	1.4
Shoulder-seat distance	23.00	1.2	21.25	1.2
Elbow-seat distance	8.75	1.1	8.0	1.1
Buttock-back of calf distance	18.75	1.0	18.25	1.0
Underside of thigh-floor height	16.50	0.8	15.50	0.8
Shoulder width	17.50	1.0	15.75	1.0
Elbow width	17.25	1.6	15.75	1.6
Buttock width	13.75	0.9	14.75	0.9

CONCLUSIONS/RECOMMENDATIONS:

(1) The paper concludes that natural postures are usually very different from the rigid ones most convenient for anthropometric surveys.

(2) There are several dimensions of chairs that are not directly governed by the dimensions specified in this paper (e.g., minimum acceptable height and depth of seat, shape of arm-rests).

(3) On the other hand, some chair dimensions depend directly on anthropometric measurements (i.e., maximum acceptable height and depth of seat and its minimum acceptable width).

CATEGORY: SEAT DESIGN

AUTHOR: Barkla, D.M.

TITLE: Chair angles, duration of sitting and comfort ratings.

CITATION: Ergonomics, 1964, 7, 297-304.

RATIONALE: Previous studies have not attempted to measure the subjective feelings of comfort in the sitters. The present study was conducted to see whether the variation in the angles of a chair would be reliably followed by changes in reports of comfort. Secondly, the study was performed to see whether ratings of comfort made after 30 minutes differed in any important way from those made after 5 minutes.

METHODOLOGY:

SAMPLE SIZE: Forty-eight British male undergraduates were used.

POPULATION CHARACTERISTICS: The subjects ages were between 18 and 20, and their height (without shoes) ranged between 172 and 178 cm.

PROCEDURES: After sitting in a chair for either 5 or 30 minutes, the S was shown a card bearing the following phrases:
The chair ______________________ for reading.
(a) coulun't feel more satisfactory
(b) feels quite satisfactory
(c) feels fairly satisfactory
(d) feels only just satisfactory
(e) feels unsatisfactory
(f) feels acutely unsatisfactory
(g) couldn't feel more unsatisfactory
The design was in a fully counterbalanced order. Ss could read magazines and smoke while sitting in the chair.

APPARATUS: The seat was flat and not shaped to fit body contour (padded with 2.5 cm. thick high-density latex foam). The back was padded by 13 mm. thick uncovered medium hardness polyether foam.
The experimental chair could be independently varied in five ways:

Angle between horizontal and main back (18-55 cm. above seat)	100°	115°	130°
Angle between horizontal and lower back (0-18 cm. above seat)	85°	100°	115°
Angle between horizontal and seat	5°	10°	15°
Seat height (at front)	46 cm.	45 cm.	44 cm.

Displacement of headrest forward from the vertical center line of the main back	0	5 cm.	10 cm.

The experimental chair had the following fixed dimensions:

Seat depth	44 cm.
Seat and back width (of. separation of arms)	50 cm.
Radius of lateral curvature of main back	80 cm.
Height of arms (above seat)	24 cm.
Separation of arms	46 cm.
Length of arms	40 cm.

SIGNIFICANT RESULTS: Successive ratings made by the same Ss showed no order effects for Ss who sat in the chair for two 30 minute sessions. Ratings made by Ss after 5 minutes of sitting were distorted by an order effect.

CONCLUSIONS/RECOMMENDATIONS:
(1) Ratings made on a simple scale, after a 30-minute exposure to the chairs, can discriminate reliably between assessments of different settings of the experimental chair used in this study. (2) Ratings on the same scale after a 5-minute exposure were substantially less sensitive and less stable than 30-minute exposures.

CATEGORY: WORKPLACE DESIGN AND MODELING

AUTHOR: Bittner, A.C., Jr.

TITLE: Reduction in potential user population as the result of imposed anthropometric limits: Monte Carlo Estimation.

CITATION: Point Mugu, California, Naval Missile Center, 1974. (TP-74-6).

RATIONALE: Moroney and Smith (1972), using data from 1549 U.S. Navy aviators, demonstrated that designing a workspace to accommodate individuals with anthropometric features within specified percentile ranges (e.g., 5th to 95th) can result in a large proportion of the user populations being excluded (i.e., 53% on 13 workspace related dimensions). This study investigated the use of a computer-based Monte Carlo Model, based on the multivariate normal distribution, to estimate the same effects. Such a model could be used to estimate proportions accommodated by a particular workspace design.

METHODOLOGY:

SAMPLE SIZE: Four hundred Monte Carlo model samples and 1549 aviators were used.

POPULATION CHARACTERISTICS: The Monte Carlo model used a correlation matrix of a Navy pilot sample; the 1549 aviators represented a "random sample" of about 10% of the 1964 U.S. Navy aviator population.

SIGNIFICANT RESULTS: The results of a computer based Monte Carlo model were found to be in close agreement with empirical (Moroney & Smith, 1972) results. Correlations between the model and empirical cumulative percents excluded were r = .997 for 5th and 95th percentile screening limits and r = .990 for 3rd and 98th percentile screening limits on 13 variables important in workspace design.

CONCLUSIONS/RECOMMENDATIONS:

(1) The Monte Carlo estimation method is a fast, convenient and accurate method for estimating accommodated percentages.
(2) It requires less storage than other computer based methods required for exclusion studies of more than two dimensions.
(3) Monte Carlo estimation can be applied to data sets which are not well defined.
(4) The validity of the Monte Carlo estimation technique has been demonstrated for estimating the accommodated percentage of Navy Pilots as anthropometric restrictions are applied.

CATEGORY: WORKPLACE DESIGN

AUTHORS: Bittner, A.C., Jr. & Moroney, W.F.

TITLE: The accommodated proportion of a potential user population : Compilation and comparisons of methods for estimation.

CITATION: Proceedings of Human Factors Society, 18th Annual Meeting, October 15-17, 1974. (Also reprinted as Pacific Missile Test Center, Point Mugu, Ca. Technical Memorandum TM - 75-46 on 30 Sept. 1975)

RATIONALE: This report catalogs, describes and compares methods for calculating the proportion of potential users accommodated when (workspace related) anthropometric restrictions are applied. It is designed to be a user's quide to available methods.

METHODOLOGY:

OTHER: Methods found in a survey of the literature were cross-classified as either (1) test fitting; (2) "modeling" or (3) "limits estimation" techniques and as appropriate for either bivariate or multivariate problems. Methods were then described, characterized as to nature, and compared as to requirements, accuracy, limitations and advantages.

SIGNIFICANT RESULTS: The paper provides a review of accommodated percentage method up to 1974, and guidance in selecting appropriate techniques.

CONCLUSIONS/RECOMMENDATIONS:

(1) This paper concludes that considerations in selecting a method for estimating the accommodated percentage are in order (a) the level of the available data; (b) the number of feature dimensions involved; and (c) the desired accuracy.

(2) It also recommends the combining of a model of the distribution of potential users (e.g., Bittner, 1974) with dynamic man models (e.g., Ryan, 1971; Kilpatrick, 1972) so that dynamic studies of workspace design accommodated percentage can be made.

CATEGORY: CONSOLE DESIGN AND REACH ENVELOPE

AUTHOR: Bullock, M.I.

TITLE: Cockpit design -- Pilot Accommodation and accessibility to controls.

CITATION: Aerospace Medicine, 1973, 44, 1295-1299.

RATIONALE: Any planned improvement to cockpit design must take account of the pilot's safe, secure, and adequate restraint, his comfortable accommodation, and his accessibility to hand and foot controls. A questionnaire was distributed to find out the opinions of civilian pilots on the use and adequacy of restraint systems, of available seat adjustments, on cockpit accommodation and on accessibility to controls.

METHODOLOGY:

SAMPLE SIZE: Three hundred and forty Brisbane male pilots were chosen at random from lists of light aircraft license holders. Sixty-seven Queensland female pilots were also used. A total of 194 replies were received (48% return).

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Although pilots using lap belts reported they used them during the flight, up to 20% of these found that they had to stretch unduly to reach the cowl flap control, the stowed microphone, the rudder trim, and the fuel tank selector.
(2) The majority of pilots considered that their seating arrangements were comfortable, only 12% noting general dissatisfaction. Only one-fifth of the pilots could adjust their seats vertically.
(3) Quite a large proportion of pilots experienced some discomfort in their cockpits, for 20% reported knocking their knees on the instrument panels, 16% had difficulty fitting their thighs under the control yoke, and 33% stated that they had inadvertently operated controls while entering or leaving the seat.
(4) Some other negative comments included: reaching some controls was difficult because of their position; bending and reaching for some controls caused a reduction in visibility; knees were frequently knocked on the control wheel.

CATEGORY: SEAT DESIGN

AUTHOR: Branton, P.

TITLE: Behavior, body mechanics and discomfort.

CITATION: Ergonomics, 1969, 12, 316-327.

RATIONALE: This paper attempts to show that the behavioral study reveals gaps in the conceptual framework on sitting and seats and suggests ways of bridging them. The major area of concern is comfort and relaxation in sitting. The limiting conditions are that the sitter's limbs perform little or no overt work and that his pelvic complex and spine rest on the seat pan and backrest.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: Several authors have shown that the angulation of the sacral plate varies with different individuals and that sitters may rotate their pelvis in an endeavor to bring the plane of the joint to the horizontal in order to reduce vertical stress. This would explain why backward-slumped postures and/or large seat-to-back angles (105° or more) are so often preferred.

CONCLUSIONS/RECOMMENDATIONS:

(1) It is unlikely that discomfort can be avoided by simply matching each body dimension with the equivalent seat dimension, as if the interface were static. What seems to be critical is the relation of any one dimension with the others and with expected sitting behavior. For instance, the relation of seat depth to seat height depends on the purposes of the seat.
(2) The provision of a moderate degree of surface roughness would add usefully to the resistance against sliding movements of the body.
(3) Coverings and upholstery of the seat should not restrict the dissipation of perspiration moisture and heat at the interface.

CATEGORY: SEAT DESIGN

AUTHORS: Branton, P., & Grayson, G.

TITLE: An evaluation of train seats by observation of sitting behavior.

CITATION: Ergonomics, 1967, 10, 35-51.

RATIONALE: The present study stated that the seat was the sitter's immediate environment and posed the question whether one seat could "cause" people to sit more in one way than in another.

METHODOLOGY:

SAMPLE SIZE: Eighteen subjects were selected from the railway office staff.

POPULATION CHARACTERISTICS: Ten males and 8 females ranging in age from 26 to 60 and representing the ranges for height and weight of the British population were selected.

PROCEDURES: Observers coded each posture. During the course of the survey, 4879 observations were made on the London-Edinburgh run. Subjects were also filmed and the subject's sitting posture were also coded.

APPARATUS: Two types of seats made up the accommodation of six carriages, three of which were compartmented, the other three being open carriages. Each of the seats had been manufactured to standard specifications, and variations within each type were insignificant. Both seats had the following dimensions:
(1) Seat height - 15.75 in.
(2) Arm rest height - 8.25 in. above seat pan.
(3) Back rest angle - 105°
(4) Height of backrest - 3 ft. 5 in.
The internal differences were that Type I was a traditional, sprung, and upholstered seat, while Type II had a glass reinforced plastic shell and urethane foam cushions of high density. Type I gave a relatively "soft" subjective feel, whereas type II appeared subjectively "firm".

SIGNIFICANT RESULTS: Taking both seats together, about 75 percent of the observed passengers did not obtain support from the headrest, about 18 percent did not use arm rests, and about 7 percent did not use the backrest. Sex differences were found to be marked (e.g., males slumped in seats more than females).

CONCLUSIONS/RECOMMENDATIONS: Types II and I represent a drastic contrast in design philosophy of "mod" versus "traditional." By almost all counts Type II is much the better. It was found that the dominant postures were maintained for longer periods of time in II than in I, especially after the first hour of sitting. At the same time passengers were on the average less fidgety in II than in I. The tendency in II to adapt better postures increased with sitting time.

CATEGORY: REACH ENVELOPE

AUTHOR: Bullock, M. I.

TITLE: The determination of functional arm reach boundaries for operating of manual controls.

CITATION: Ergonomics, 1974, 17, 375-388.

RATIONALE: The investigation was initiated to define the functional arm reach boundaries by 95 percent of male and by 95 percent of female pilots and to indicate their accessibility to controls while firmly restrained with lap and sash harness in cockpits of some present light aircraft for planning of the manual workspace of automobiles and aircraft cockpits.

METHODOLOGY

SAMPLE SIZE: Seventy five males and 35 females were used.

POPULATION CHARACTERISTICS: The subjects were Australian pilots who were exactly representative of the height and weight distributions for the pilot population.

CLOTHING: Subjects wore short-sleeve shirts.

PROCEDURES: The physical measurements taken on each subject included stature, weight, right and left shoulder height, biacromial breadth, sitting eye height, knee height, popliteal height, chest depth, abdominal depth, buttock-knee length, arm reach forward (both to thumb and fingertip), and leg length. The subject was positioned and seat adjustments were recorded for pilot comfort. Measurements were taken on both arms on a series of 13 horizontal levels, 13 cm. apart at angles of -15°, 0°, 15°, 30°, 60°, 90°, and 110° to the midline. Subjects were asked to push lighted buttons without sliding from beneath the shoulder strap trunk movements were verbally standardized by the experimenter. Repeatability tests were given to check consistency of measurements on 3 subjects.

APPARATUS: A rotating chair with an adjustable seat and backrest, a control wheel, an adjustable footrest, a vertical measuring rod suspended from a horizontal rail fixed above the seat reference point (SRP), a lap and sash harness, and an automatic measuring system were used. A control wheel was attached to the apparatus so that the pilot could grasp it with one hand while the other was reaching towards the arm measuring device. The control wheel was positioned 30 cm. above the SRP with anterior adjustability. The functional arm reach measuring device included a vertical rod which moved along the mid-saggital plane in the 0° position through the SRV, 150 cm. anteriorly. There were 13 colored flat buttons (1.5 cm in diameter from 30 cm. below to 126 cm. above SRP at 13 cm. intervals) along the rod.

SIGNIFICANT RESULTS: Measurements were given which indicated the distances from the Seat Reference Vertical (SRV) to which 95 percent of the male or the female populations could reach. A comparison of the maximum distances which may be reached by 95 percent of the male and by 95 percent of the female pilot population shows a fairly consistent pattern of differences between the two. The size of the female reach envelope was smaller in every direction. Correction factors were given for change of grip, change in backrest angles and restraint conditions.

CONCLUSIONS/RECOMMENDATIONS: The method set forth in this report is satisfactory for accurate and rapid data collection. It is flexible enough for the determination of the space envelopes relevant to the accommodation and work area conditions within various other vehicles and cockpits.

CATEGORY: SEAT DESIGN

AUTHORS: Burandt, U. & Grandjean, E.

TITLE: Sitting habits of office employees.

CITATION: Ergonomics, 1963, 6, 217-228.

RATIONALE: The study was conducted to see whether employees adjust their postural habits to the criteria of comfort. The investigation included the extent to which the orthopaedically based recommendations actually correspond to the subjective feeling of comfort.

METHODOLOGY:

SAMPLE SIZE: 378 Ss (261 males and 117 females)/For comfort of seat heights, the study used 48 males and 20 females.

POPULATION CHARACTERISTICS: clerical workers
Height unshod Males 172.8 cm. S.D.=9.02 Females 162.4 cm. S.D.=14.08
Knee height shod Males 55.2 cm. S.D.=2.8 Females 52.9 cm. S.D.=2.7

PROCEDURES: 246 Ss were observed in sitting postures 20 times at intervals exceeding 2 minutes. Ss also filled out a questionnaire.

APPARATUS: For the comfort of seat heights, a fixed chair (Stoll Giroflex, Model No. 1735 FK) was used. The distance between seat and table top was 28 cm.

OTHER: The floor panel was raised and lowered at 2 cm. intervals. Ss filled out a questionnaire indicating which height adjustment was most comfortable and the admissible lower and upper limits.

SIGNIFICANT RESULTS: The most frequent seat heights were between 26 to 30 cm. beneath the upper table edge (mean value = 28.5 cm.). Comfort of the upper part of the body is the determining factor for the selection of the seat height. Fewer complaints were given for the 78 cm. office table than other heights of table size. Complaints in the thighs are caused mainly by shifting the weight of the body to the thighs owing to job requirements, and not so much by seat height. When backrests were used, adjustable backrests were used more frequently than rigid ones.

CONCLUSIONS/RECOMMENDATIONS: The following recommendations were established for office seats.

(1) Seat height adjustability should be between 40 and 53 cm. (for office tables 78 cm. high between 45-53 cm., for office tables 70-74 cm. high between 40-48 cm.).
(2) Vertical adjustability of the backrest from seat level to lumbar support should be from 14-24 cm.

(3) Adjustability of rest depth should be from 34 to 44 cm (referred to front edge of the seat).
(4) Depth of the seat should be between 35-40 cm.
(5) The necessary space range between seat height and table top should be 27-30 cm.
(6) Inclination of seat pan in back should be 3°.
(7) The backrest height should be 20 cm.
(8) The inclination of seat to backrest should be 100°.
(9) Foot rests heights should be adjustable up to 10 cm for 78 cm high office desk and 5 cm for 72 cm high office desks.

Akerbloom (1948) and Keegan (1962) recommended lower seat heights because of undue pressure and discomfort in the thighs caused by higher seats. Burandt and Grandjean found that complaints in respect to thights were not found to be above average for short people, but for particular types of jobs, which demand a forward inclined posture with arms resting on a support. Consequently, discomfort in thighs is not due as much to chair seat height, as to the type of occupation.

CATEGORY: REACH ENVELOPE AND MODELS

AUTHORS: Chaffin, D. B., Schutz, R. K., and Snyder, R. G.

TITLE: A predictive model of human torso volitional mobility.

CITATION: SAE Transactions, 1972, 81, pt. 1, 24-38.

RATIONALE: The purpose of this study was to derive a set of models which describe the configuration of the internal, torso-skeletal system from data previously collected utilizing photogrammetry and radiography. These models utilized ten surface markers instead of the traditional two or three solid links.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) The General Model gives predictability in the widest sense not utilizing anthropometric variables.
(2) The Anthropometric Model utilizes six anthropometric variables; stature, sitting height, chest circumference, biacromial breadth, humeral length, and weight. Predictability variance was 2.5 to 3.5 times greater than pure subject variance. Variance not explained by the model is probably due to individual differences in muscular development, joint/ligamentous structures, etc.
(3) The data used was 48 sitting positions with ten markers each described in three-dimensional coordinates.

CATEGORY: SEAT DESIGN

AUTHOR(S): Chidsey, K.D. & Shackel, B.

TITLE: The need for the experimental approach in the assessment of chair comfort.

CITATION: Paper presented at the Ergonomics Research Society Annual Conference, 1966. Abstract in Ergonomics, 1966, 9, 340.

RATIONALE: Three approaches could be adopted in selecting chairs when considering comfort: (1) opinion, (2) interpretation based on British Standard recommendations, and (3) evaluation experiments. These three approaches were used by eight ergonomists to see which were valid.

METHODOLOGY:

SAMPLE SIZE: Eight Ergonomists from Britian used the three chair selection methods.

PROCEDURES: Chairs were ranked by sitting in them, then relevant information on the 10 chairs with respect to B.S.I. recommendations and specifications were given the Ss. Finally the Ss could both sit in the chairs and were given the dimensions of the chairs.

APPARATUS: Ten upright chairs were used.

SIGNIFICANT RESULTS: The results failed to support the validity of the opinionative assessment or of the interpretation based on the B.S.I. recommendations. The only valid approach was the experimental method used by ergonomists.

CONCLUSIONS/RECOMMENDATIONS: N/A

CATEGORY: SEAT DESIGN

AUTHORS: Chidsey, K.D., Shackel, B., & Shipley, P.

TITLE: A comparative study of seat comfort with upright chairs.

CITATION: Paper presented at The Ergonomics Research Society, Annual Conference, 1966. (Abstract in Ergonomics, 1966, 9, 339-340).

RATIONALE: The primary aim of this study was to compare a group of similar chairs in terms of the comparative comfort they afforded in several typical usage situations.

METHODOLOGY:

SAMPLE SIZE: Twenty subjects (10 males and 10 females) were used.

POPULATION CHARACTERISTICS: The subjects were selected to cover as far as possible the normal population in body height and within ± 1 S.D. of the mean weight for their height.

PROCEDURES: A questionnaire was developed embodying a general comfort rating scale and ranking of body - area comfort. The questionnaire was administered at suitable intervals during each subject's trial. In addition, the activity sampling method of observation was explored. Objective measurements were made of the main dimensions of the chairs for comparison with the values recommended in the most relevant British Standard. There were three different studies under three conditions: (1) long-term sitting in the laboratory, (2) in the office situation, and (3) in the canteen situation.

APPARATUS: Ten chairs, five of which were polypropylene and five others of equivalent price and type, were used.

SIGNIFICANT RESULTS: In the long-term sitting situation in the laboratory, there was a clear decrease in the comfort level ratings with time, and three groups of chairs separated out.

CONCLUSIONS/RECOMMENDATIONS: Clear and significant separation of the chairs into at least three groups was found in each of three test situations. The best and the worst chairs were consistently the same for all three test situations and for all measurement methods used.

CATEGORY: ANTHROPOMETRY

AUTHOR(S): Churchill, E., McConville, J.T., Laubach, L.L. & White, R.M.

TITLE: Anthropometry of U.S. Army Aviators - 1970

CITATION: Technical Report 72-52-CE, Natick, Massachusetts: U.S. Army Natick Laboratories, Dec., 1971.

RATIONALE: This report describes an anthropometric survey of U.S. Army aviators conducted at Ft. Rucker, Alabama in 1970. Data for 85 body measurements were gathered on a sample of 1482 flying personnel.

METHODOLOGY

SAMPLE SIZE: 1482 males were Ss.

POPULATION CHARACTERISTICS: All Ss were involved in one way or another with aircraft of the U.S. Army.

CLOTHING: Ss were nude, except for underwear.

PROCEDURES: Ss sat erect on a cushionless flat surface with their feet on an adjustable foot rest so that the knees were flexed to 90°, and the long axes of the thighs were parallel. The trunk was erect without stiffness; the head was also erect with the path of vision parallel with the plane of the floor.

APPARATUS: Apparatus includes:

Anthropometer, Siber Hegner #101
Sliding Caliper, Siber Hegner #104
Spreading Caliper, Siber Hegner #105
Caliper Gauge, Siber Hegner #219
Steel Tapes, Lufkin
Lange Skinfold Caliper
Footboard and block
Headboard and block
Table measuring and wall measuring board.

SIGNIFICANT RESULTS:

Measurement	Mean	S.D.
Age	26.21 yrs.	5.51 yrs.
Weight	171.15 lbs.	23.84 lbs.
Stature	174.56 cm	6.33 cm
Shoulder height	143.06 cm	5.92 cm
Sitting height	90.92 cm	3.23 cm
Eye height (sitting)	78.80 cm	3.16 cm
Midshoulder height (sitting)	62.90 cm	2.77 cm
Elbow rest height (sitting)	23.10 cm	2.65 cm
Thigh clearance height (sitting)	14.71 cm	1.41 cm

Measurement	Mean	S.D.
Knee height (sitting)	53.01 cm	2.57 cm
Popliteal height (sitting)	42.34 cm	2.47 cm
Shoulder-Elbow length	36.71 cm	1.78 cm
Elbow-finger tip length	48.14 cm	2.10 cm
Buttock-popliteal length	48.09 cm	2.59 cm
Buttock-knee length	60.19 cm	2.63 cm
Buttock-heel length	112.17 cm	4.99 cm
Functional reach (standing)	79.34 cm	4.12 cm
Vertical arm reach (sitting)	143.48 cm	5.81 cm
Shoulder breadth	47.40 cm	2.56 cm
Forearm-forearm breadth	50.58 cm	4.46 cm
Hip breadth (standing)	35.12 cm	2.13 cm
Hip breadth (sitting)	37.80 cm	2.72 cm

CONCLUSIONS/RECOMMENDATIONS: A comparison was drawn between the 1959 study by White and the present study. In the 1959 study, 500 Army aviators were measured. Sitting height and eye height (sitting) are slightly higher for the 1970 aviators. In summary, the series of U.S. Army aviators of 1970 are 4 years younger, about 5 lbs. heavier and .75 inch shorter than the aviators in 1959.

CATEGORY: ANTHROPOMETRY, SEAT DESIGN, AND WORKPLACE DESIGN

AUTHOR: Croney, J.

TITLE: Anthropometrics for Designers.

CITATION: New York: Van Nostrand Reinhold Co., 1971.

RATIONALE: To be a successful designer of products for a part, or the whole, of a human environment, a designer must be conversant with different types of human physique and be informed about the limitations of human performance. This book provides an illustrated account of man's dimensions and other physical data, and defines their limitations and comments on any peculiarities.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Seat width: A comfortable width is 18 in. and nothing less than 17 in. is tolerable for lengthy periods.

(2) Seat height: In general, if a seat is too high a person's body will slide forward. On the other hand, if a seat is too low the seated posture will assume a forward crouch. An adjustable seat height should range from 14.5 in. to 18.5 in. for males, and from 14 in. to 17.5 in. for females. A reasonable fixed seat height for males should be 16.5 in. but for females 15.25 in.

(3) Seat depth: A suitable seat depth is 15 in. based on back of knee to buttock measurement. The seat should not cut into the back of the user's knee.

(4) Seat composition and shape: Anatomically it is the ischial tuberosities that carry the body's weight in the seated position. The seat surface needs to be soft, but the surface must also exert a counter-pressure and not submit weakly to the body's weight. A depression of 0.5 in. in a padded seat is enough. Sculptured seat surfaces with slight depressions carved to take the bony protuberances can only expect limited use. A rounded seat front edge is good.

(5) Backrest: A slightly tilted backrest helps the user to settle comfortably in a chair and prevents a gradual slide forward of the body. The backrest angle depends on the type of activity in which the operator is involved: 5-20° (for alert or attention sitting); 20-30° (conference sitting, relaxed travelling position); 45° (reclining in comfort). The backrest should support the lumbar region. It should be raised clear of the sacral region. The space between the seat pan and backrest should be 6-7 in. The height of lumbar support should be 4-6 in. for males and 8 in.

for females. For working positions, the backrest should be about 12-14 in. wide to give free space for elbows.

(6) Arm rests: Arm rests are used for arm leverage in working positions and for getting in and out of a chair. A useful distance between arm rests is 19 in. The arm rest height should be 8 in. if fixed and 7.5 in. to 10.0 in. if adjustable.

(7) Foot rests: The angle between the lower leg and the base of the foot should be 90° to 100°. If the surface of the foot rest pan is greater than 15° from the horizontal, a heel stop should be provided.

(8) Workplace Design: The minimum height to accommodate knee height is 25.5 in. The minimum sitting clearance from the back of the seat to the accommodation of the feet is 4.6 in. The minimum clearance for the thigh from the seat pan to underside of the work surface is 9 in.

CATEGORY: ANTHROPOMETRY

AUTHORS: Damon, A., & Randall, F. E.

TITLE: Physical anthropology in the Army Air Forces.

CITATION: American Journal of Physical Anthropology, 1944, 2, 293-316.

RATIONALE: The need for exact knowledge of human variations and dimensions is even greater in aviation than in the older military and naval arms, because of the paramount importance of space. Flyers must be fitted into spaces which are initially kept to a structural minimum by aircraft designers. This paper was a general overview of how anthropometric measurements were used.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: This paper reviews how anthropometric data was supplied for the location of seats and windows in cargo and troop-carrying planes. In addition, the paper reviews how a new seat back was designed based on the dimensions of the troops.

CATEGORY: ANTROPOMETRY

AUTHOR: Daniels, G.S.

TITLE: The "average man"?

CITATION: Wright-Patterson Air Force Base, Ohio: Wright Air Development Center, Technical note WCRD 33-7, December, 1952.

RATIONALE: The "average man" is a very prominent figure. As a general rule, he is used as an oversimplified means of describing the combined characteristics of a varied population. This paper points out and explains some of the factors that lead to difficulties arising from the use of "average" dimensions.

METHODOLOGY:

SAMPLE SIZE: 4,063 subjects were used.

POPULATION CHARACTERISTICS: The subjects consisted of Air Force flying personnel.

PROCEDURES: One hundred thirty-one measurements were taken on over 4,000 subjects, but only a small number of these measurements were selected for this study.

SIGNIFICANT RESULTS: In the attempt to find an "average man", the "approximately average" ranges of each measurement were used as hurdles in a step-by-step elimination. Out of the 4,063 men, only 1,055 fell in the approximately average stature. Out of these 1,055 men, only 302 were of approximately average chest circumference. At the end of 10 steps there was not a single individual remaining who fell within the "average" range of all measurements. The 10 measurements and their means were as follows:

Measurement	Mean	S.D.
Stature	175.5 cm.	6.2 cm.
Chest Circumference	98.6 cm.	6.2 cm.
Sleeve Length	85.5 cm.	3.8 cm.
Crotch Height	83.4 cm.	4.4 cm.
Vertical Trunk Circumference	164.6 cm.	7.3 cm.
Hip Circumference (Sitting)	106.0 cm.	7.2 cm.
Neck Circumference	38.0 cm.	1.9 cm.
Waist Circumference	81.4 cm.	7.7 cm.
Thigh Circumference	56.9 cm.	4.4 cm.
Crotch Length	71.6 cm.	5.1 cm.

CONCLUSIONS/RECOMMENDATIONS: This study concludes that it is virtually impossible to find an "average man" in the Air Force population. This is not because of any unique traits of this group of men, but because of the great variability of bodily dimensions which is characteristic of all men.

CATEGORY: ANTHROPOMETRY, SEAT DESIGN, AND WORKPLACE DESIGN

AUTHORS: Damon, A., Stoudt, H.W., & McFarland, R.A.

TITLE: The Human Body in Equipment Design.

CITATION: Cambridge, Massachusetts: Harvard University Press, 1966.

RATIONALE: The book guides the designer of equipment involving human body size and mechanical capabilities. Specific recommendations were presented for many major biomechanical features of man-machine integration, together with data and methods applicable to the solution of other problems. Several anthropometric tables were presented for both military and civilian populations.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

Recommendations for general seating dimensions:
(1) Seat height: 15-16 in.
(2) Seat length: 16-17 in.
(3) Seat breadth: (min.) 18 in.
(4) Backrest length: 18-20 in. (for shoulder support)
34 in. (for head support)
5-6 in. (for lumbar support; with bottom edge 5 in. above the seat)
(5) Backrest breadth: (min.) 20 in.
(6) Seat angle: 6-7°
(7) Backrest angle: 115°
(8) Height of workspace: 29 in.
25.0-25.6 in. for typewriting desk
(9) Floor to underside of desk: 25 in.
(10) Armrest height: 8-10 in. above seat level

CATEGORY: SEAT DESIGN

AUTHORS: Darcus, H.D. & Weddell, A.G.M.

TITLE: Some anatomical and physiological principles concerned in the design of seats for naval war weapons.

CITATION: British Medical Bulletin, 1947, 5, 31-37.

RATIONALE: The seat must support the body in a normal comfortable position and must be so placed that the operator is in the optimum relation to his work. This paper was concerned with the design of seats for use in naval optical-sights.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The main consideration in the design of seats for use in naval optical sights was stability. Stability was achieved by the use of counterpressure between the feet and the backrest. The ideal chair for body stabilization should encompass the following points:

- (a) The backrest should fit in the lumbar region.
- (b) The ischial tuberosities should bear most of the weight.
- (c) The seat should be made adjustable; seat must be able to be adjusted 4 in.
- (d) The back of seat cushion should be firm and resilient; front of seat cover should be soft and resilient.
- (e) Knee-angle should be 160°.
- (f) Foot-rest should move upwards and towards seat to accommodate smaller persons.
- (g) Foot should be at right angles to legs. A heel rest should be provided.
- (h) Thigh should be horizontal.

It was concluded that the ideal position for body-stabilization in ocular sights was with the user's thighs horizontal and the knee-angle at 165°. The authors recommend the following dimensions:

- (1) Width of seat cushion should be 15 in. at a minimum.
- (2) Depth of seat cushion should be approximately 18 in.
- (3) The front 8 in. of the cushion should be sloped to an angle of 10° to the horizontal and the back 10 in. disposed horizontally.
- (4) Length of footrest should be 14 in.
- (5) Width of footrest should be approximately 15 in.
- (6) Backrest should be 5 in. in vertical depth with its center placed 10.5 in. above the compressed seat-cushion.
- (7) Width of backrest should be 15 in.
- (8) Backrest should be placed behind the back edge of the seat.

CATEGORY: ANTHROPOMETRY

AUTHOR: Dempster, W. T.

TITLE: The anthropometry of body action.

CITATION: In Dynamic Anthropometry, Annals of New York Academy of Science, (ed.) R. W. Miner, 1955, 63 (4), 559-585.

RATIONALE: This report is an analysis of dynamic anthropometric characteristics in terms of the engineering properties of the skeletal and joint system (in terms of an open-chain link system). The paper reviews the properties of movement in terms of the link system.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The development of dynamic anthropometry must proceed on the basis of body kinematics and the relationships of force to posture and movement. Movement studies are necessary. Subjects should be selected so as to allow matching of definite dimensions with those of the target population. Static movement can not generalize to dynamic measures, but can be used as a basis for selection of dimensions for dynamic study.

CATEGORY: REACH ENVELOPE

AUTHORS: Dempster, W.T., Gabel, W.C., & Felts, W.J.L.

TITLE: The anthropometry of the manual work space for the seated subject.

CITATION: American Journal of Physical Anthropology. 1959, 17 (4) 289-317. Also published in ASD TR 61-89, USAF, WPAFB, Ohio, 1961. (AD-258564).

RATIONALE: This paper explored the space-geometry of hand motions as they relate to young men in the seated posture. The space itself is merely the region of potential position of the hand point. The envelope has a specific size, shape and relation to the seat, trunk and legs. The paper defines many terms such as rotational (angular) movement and translational movement of the hand mass.

METHODOLOGY:

SAMPLE SIZE: Twenty-two male college students (ages 17-33) were used.

POPULATION CHARACTERISTICS: In build, the subjects ranged from medium to muscular. The subjects dimensions were as follows: stature--175.7±4.5 cm.; sitting height--91.5±3.2 cm.; acromial height (sitting)--61.3±3.2 cm.; upper limb length--72.8±2.9 cm. (acromion to dactylion III--arm straight, horizontal, and forward). The dimensions of these subjects are a little higher than the mean of the average population.

MAN/HARDWARE RELATIVE RELATIONSHIP: The vertical adjustment between eye level and heel was made a standard 39.5 in. for each S.

PROCEDURES: Experimenters used photo records of time exposures showing the motions of a tiny neon lamp at the hand grip. The reference point was the midsagittal point of the junction of the seat and back. After each exposure, the seat and S were advanced by a standard distance (6 in.) until the S no longer had space to move his hand, the reference grids, and his body. All records were taken from the left hand. Lights were attached to the yoke over the sternum to indicate whether or not trunk movement contributed to hand range.

APPARATUS: The seat, made out of wood, was 15 in. deep and 11 in. wide. The S's elbows and shoulders were unimpeded. The seat tilted 6° to the horizontal. The backrest was 26 in. in height. The backrest was tilted back 17° from the vertical. An adjustable dental headrest was mounted at the top of the seat back. Footrest and foot platform relative to the seat could be adjusted by oblique upward and forward movements. The hand appliance consisted of a handle (a 30 mm. aluminum rod) and a small rectangular orientation grid. A dental moulding compound was shaped about the handle. Eight grid positions were obtained by screwing the grid to the ball at standard angulations. There were five grip orientations in the sagittal plane (relative to the room): (1) -30°, (2) 0° vertical, (3) 30° forward, (4) 60° forward, (5) 90° forward (grip horizontal and directed forward). Three other grips included the prone, supine and inverted positions. A large 5x7 ft. mirror set at 45° showed a side view of the subject and seat.

SIGNIFICANT RESULTS: As the S-to-grid was shortened, the size of the circuits increased, especially in the upper range. As the seat-grid distance was further reduced, a lower limit was imposed by contact with the knees and thighs. After trunk contact with the wrist and forearm, the only territory free for additional limb and hand movement was lateral to the trunk on the test-limb side of the body. These contours became narrow vertical ellipses, with the upper pole tending to deviate toward the head. Each of the 8 grips had characteristic differences in dimensions. Linear dimensions of the upper limbs are metrically correlated with the extent of hand range, thus the longer-limbed Ss were able to reach father upward, downward, laterally, and medially across the trunk, as well as father forward and backward. Because of the variability between Ss, more critical placement of controls in the work place is necessary when planned for the 90°, 60° and supine positions of the hand than for the 0°, -30°, 30° and prone hand orientations.

CONCLUSIONS/RECOMMENDATIONS: The common region for the 8 hand orientations was roughly 15 in. wide, 16-18 in. high and 18-24 in. deep; it lay obliquely, and its maximum anteromedial to posterolated extent was about 30 in. with a perpendicular breadth of 18 in. at the maximum dimension. The authors present a workspace plan based upon their analysis.

CATEGORY: WORKPLACE DESIGN

AUTHORS: Duncan, J. & Ferguson, D.

TITLE: Keyboard Operating Posture and Symptoms in Operating.

CITATION: Ergonomics, 1974, 17, 651-662.

RATIONALE: The purpose of this paper was to analyze the relationship between postures and symptoms in operating.

METHODOLOGY:

SAMPLE SIZE: Ninety male subjects, who complained of symptoms in operating and who were diagonosed as suffering from occupational cramp and/or myalgia, and forty-five unaffected telegraphists of corresponding sex, age, length of service and status were used.

PROCEDURES: Operating postures were reported by observations made independently by a physician and a physiotherapist.

SIGNIFICANT RESULTS: In general, adverse operating postures were noted more often in subjects with symptoms of occupational cramp and myalgia than in unaffected teleprinter operators. Adverse operating postures of arm and hand were more often right than left sided (when they were not bilateral) and more common in subjects than controls. The part of the limb affected was usually associated with some adverse operating posture of that region.

CONCLUSIONS/RECOMMENDATIONS: The findings support the conclusion that keyboard design and work height lead to ill-advantaged postures, repeated adoption of which gives rise in some operators to recurrent symptoms of incoordination and muscle pain.

CATEGORY: WORKPLACE DESIGN

AUTHOR: Ellis, D.S.

TITLE: Speed of manipulative performance as a function of work surface height.

CITATION: Journal of Applied Psychology, 1951, 35, 289-296.

RATIONALE: The paper investigated the speed of performing a simple manipulative task as a function of work-surface height.

METHODOLOGY:

SAMPLE SIZE: Forty-eight males were used.

POPULATION CHARACTERISTICS: The subjects were undergraduate psychology students.

PROCEDURES: The task was the Minnesota rate of Manipulation Test. The task consisted of turning blocks over in holes with both hands. Each subject served in two 45 min. sessions which were 48 hours apart. Each session contained six 3 minute trials at 6 different work surface height levels. At the end of the last trial, the subject was asked to put the work surface at his optimal height.

APPARATUS: The apparatus included a plywood working surface attached to two collars which rode on 1.25 in. pipe. The work surface was illuminated 30 in. above the work surface.

SIGNIFICANT RESULTS:

(1) The optimal performance was found at the height which was 42 in. above the floor.
(2) The minimum muscular strain also occurred at this height.
(3) The locus of muscular strain for the back and the legs was maximal at lower heights, while for the upperarm and shoulder, it was maximal at higher heights.
(4) The average preferred height by subjects was 41.3 in. ± 2.5 in.

CONCLUSIONS/RECOMMENDATIONS: The study concludes that muscular tension is an intervening variable between work-surface height and performance. Work-surface height is an equipment design variable which needs to be investigated since these results are minimally applicable to an industrial setting.

CATEGORY: WORKPLACE DESIGN

AUTHORS: Ely, J. H., Thomson, R. M., & Orlansky, J.

TITLE: Layout of Workplaces (Chapter 5 of the Joint Services Human Engineering Guide to Equipment Design).

CITATION: Wright Air Development Center, 1956, WADC Technical Report 56-171.

RATIONALE: A critical factor affecting operator performance in any man-machine system is the layout of his workplace. This report provides a compiltation of human engineering recommendations concerning various aspects of workplace layout.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Assign to the hands, controls which require high precision and/or speed of operation.

(2) Assign to feet controls which require large applications of force.

(3) When the seated operator must apply a force of more than 5 lbs. to a control by one hand, provide the operator with a support, e.g., back rest for pushing, foot rest for pulling.

(4) Design the workplace so that the operator can move his trunk or entire body, particularly when heavy forces (30 lbs.) or large movements (more than 15 in. in a fore-aft direction) must be made by the hands.

(5) For some hand controls, provide an elbow rest.

(6) For instruments whose displays are located close to their controls viewing distance is limited by reach distance and should not exceed 28 in. Viewing distance to displays should never be less than 13 in. and preferably not less than 20 in.

(7) Recommended dimensions of optimum manual areas (width is approximately 24 in.) include:

(a) Near low - operator's elbows next to body, forearms horizontal.

(b) Near high - operator's elbows next to body, forearms flexed upward about the elbow 15^{o}.

(c) Far high - operator's arms extended horizontally from shoulder, operator sitting erect.

(d) Far low - operator's arms extended and lowered until hand is at level of elbow in "near low" position.

(8) If a back rest interferes with rearward movement of the elbows, no control should be placed within 16 in. (in any direction) of the resting position of the elbow.

(9) The seat reference point should be adjustable at least 3 in. horizontally and 5 in. vertically.

(10) The operator should always be provided with a foot rest which allows each foot to be normal (90^{o}-100^{o}) to the lower leg. If the foot rest is at an angle of more than 20^{o} from the horizontal, a heel support (between 1.0 and 1.5 in. thick to minimize interference with leg movements) should be provided to prevent the foot from sliding downward.

CATEGORY: WORKPLACE DESIGN

AUTHOR: Ferguson, D., and Duncan, J.

TITLE: Keyboard Design and Operating Posture.

CITATION: Ergonomics, 1974, 17, 731-744.

RATIONALE: The present study attempted to explore effects of design on the operator, and to examine how layout could be changed to obviate postulated adverse effects.

METHODOLOGY:

SAMPLE SIZE: Twenty-nine male telegraphists, affected with occupational cramp or myalgia. Sixty-one male telegraphists, who said they had some symptoms in operating even if of minimal degree. Forty-five unaffected telegraphists (of similar age, sex, and operating experience) were used.

APPARATUS: At the beginning of the experiment, bench height was relatively high (71 cm.) and footrests were not provided. Trainees were not instructed in the adjustment of their chairs. The Es added wide and deep wooden foot stools that were easily adjustable in height and rake.

SIGNIFICANT RESULTS: A trial of correction of chair height by elevation aided elimination of the extended wrist action in operating.

CONCLUSIONS/RECOMMENDATIONS: A bench height of no more than 64 cm. with low or countersunk keyboard (or a bench of adjustable height) and a seat height adjustable between 38 and 48 cm. would have been necessary to obviate the postural difficulties observed.

CATEGORY: SEAT DESIGN

AUTHORS: Floyd, W.F. & Roberts, D.F.

TITLE: Anatomical and physiological principles in chair and table design.

CITATION: Ergonomics, 1958, 2, 1-16.

RATIONALE: The paper reviews the general anatomical and physiological principles, as well as anthropometric data which can be applied to the design of furniture, especially chair and table design.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Change in postures is extremely important in relation to muscle activity and fatigue. A chair should permit changes of posture.
(2) Comfort is at a maximum when the weight of the trunk is borne mainly by the ischial tuberosities. Thighs are anatomically and physiologically unsuited for supporting the weight of the sitting body.
(3) The height of the seat should be determined principally by the desirability of avoiding undue pressure on the soft tissues of the posterior aspect of the thigh.
(4) A seat depth of 15 inches measured from the front edge of the seat to the projected line of the backrest would be suitable for over 99% of the male population. The average distance from the popliteal angle to the sacral plane was 17.9 in. S.D. = 0.9 in. (sample of 285 British males).
(5) A seat width of 16 inches will suit all except the broadest individuals, with chair arms there should be 19 in. between armrests (thigh breadth of 115 seated British males was 15.9 in. S.D. = 1.1 in.).
(6) The backrest is most effective within the range of the 2nd to the 5th lumbar vertebrae. The distance of the backrest to the seat of the chair should be between 8-13 in. The radius of the backrest should not be less than 12 in. while 16-18 in. is preferred.
(7) A horizontal seat or one with a slope of less than 3° backwards is suitable for jobs which require upright or a forward leaning trunk.
(8) Table height is closely correlated to elbow height. Elbows should be about the level of the working plane. The space between the under surface of the table and the chair seat should be slightly greater than thigh thickness.
(9) The seat height should be 17 inches.

CATEGORY: WORKPLACE DESIGN

AUTHORS: Floyd, W.F. & Ward, J.S.

TITLE: Posture in industry.

CITATION: International Journal of Production Research, 1967, 5, 213-224.

RATIONALE: There is a need to study the dimensional relationship between the operator and his machine so that the working posture of the operator can be improved. The present paper reviewed three studies of postural behavior in industry.

METHODOLOGY: N/A

SIGNIFICANT RESULTS:

(1) In the first study the bench at which the workers sat was of the following dimensions: Seat height - 24 in.; Seat width - 10.5 in.; and Seat height to bottom of table - 4 in. The subjects' thighs could not be accommodated causing subjects to sit on the edge of the bench. Chairs with back rests were tried and the work table was redesigned.

(2) The second study took place in a firm where the women assembled, soldered and inspected fuses. Most of the subjects did not use the backrest. The height of the work bench was reduced to 27 in. from the floor, and adjustable seats were added. Most women thought that the seat height of 16 in. above the floor was most comfortable. The top of the backrest was 13.2 in. and buttocks fully supported by the chair seat.

(3) The third study dealt with work surface height and the standing position. Using a stamping (notching) machine, the experimenters raised the working surface until the surface was 3 in. below the level of the elbow when the individual was holding the forearm at right angles to the vertical upper arm.

CONCLUSIONS/RECOMMENDATIONS: N/A

CATEGORY: SEAT DESIGN

AUTHORS: Floyd, W. F., & Ward, J. S.

TITLE: Anthropometric and physiological considerations in school, office and factory seating.

CITATION: *Ergonomics*, 1969, 12, 132-139.

RATIONALE: Sitting habits acquired in the schoolroom are likely to be carried over into later commercial or industrial employment. If an individuals' early training has taught him good postural habits with correctly dimensioned and designed furniture, he is likely to require that his subsequent commercial or industrial workplace be such that he can maintain the same postural habits. Consequently, it is of great importance to place emphasis upon the further study and analysis of postural behavior in the schoolroom.

METHODOLOGY:

SAMPLE SIZE: Forty-two girls and 42 boys (mean-17.2 yrs.) were used. The mean height of the boys was 174.5 cm. and for the girls 163.1 cm. The mean lower leg length of boys was 45.2 cm., and for girls 41.7 cm. while wearing footwear.

PROCEDURES: The behavior of the subjects was observed by a multimoment technique.

SIGNIFICANT RESULTS: The characteristic postures of schoolchildren include: straight trunk, straight shoulders, straight leg, trunk supported by arms, and backrest being used. The most frequent sitting behavior was a desk-supported posture. In addition, a pilot electromyographic investigation was conducted on one schoolboy to obtain recordings from some of the muscles considered to be active in the seated working position: trapezius (neck) cervical position; trapezius (posterior) mid-clavicular portion; latissimus dorsi post-axillary fold; erector spinae lumbar region. The lowest electrical activity occurred when the backrest was used (i.e., minimum activity occurred in all 4 pairs of muscles), as compared to postures where the trunk was slumped forward and the arms (either one or both) were resting on the desk surface whether the S was writing or not.

CONCLUSIONS/RECOMMENDATIONS: The paper concludes that further studies in myography may be valuable in determining the postural behavior, in addition to basic anthropometric requirements, that should be considered in the dimensions and design of seats.

CATEGORY: SEAT DESIGN

AUTHOR: Garner, J.

TITLE: Proper seating: An aid to industrial efficiency.

CITATION: Industrial Medicine, 1936, 5, 324-327.

RATIONALE: The paper demonstrated that proper seating and industrial efficiency are positively correlated and made recommendations concerning proper seating. This article initially discussed fatigue and its causes, then related fatigue to improper posture and reduced performance which comes from improper seating. The deleterious effects of improper seating and posture upon the body are discussed at length. A case was made for these effects being relatively permanent if improper seating was continued over a long period of time (such as in one's profession).

METHODOLOGY: N/A

SIGNIFICANT RESULTS: Proper seating posture will at all times favor full lung capacity breathing, oxidation of the blood in a minimum of time, free exhalation of carbon dioxide, unrestricted functions of the eliminatory systems, lessened expenditure of nerve force, and a reduction in muscular efforts. These conditions tend to increase body resistance, to eliminate fatigue, and to promote better health as a whole.

CONCLUSIONS/RECOMMENDATIONS:

(1) The major conclusion of this article was that improper seating and/or slouch lead to increased muscular effort and thus to the increased production of fatigue.

(2) To prevent fatigue, a chair should be completely adjustable to the individual.

(3) A chair should embody the following features to prevent fatigue:

(a) Height from the floor must be adjustable so that the feet rest flat upon the floor with the knee at a 90° angle.

(b) The seat should not extend so far forward as to impinge upon blood vessels and nerves in the popliteal space at the back of the knee, and not so far backward as to exert pressure upon the coccyx.

(c) The seat should slope from before backward, a drop of approximately 1 inch in 12, so as to encourage gravitation toward the back of and into the chair.

(d) The chair back should not exceed 5 inches in depth (perpendicular) and should be adjustable in both the vertical and horizontal planes. Contact between the back itself and the rear edge of the seat should never be permitted.

(e) Special types of work may necessitate special construction in order to meet the above requirements.

CATEGORY: ANTHROPOMETRY

AUTHORS: Gifford, E.C., Provost, J.R. & Lazo, J.

TITLE: Anthropometry of Naval Aviators - 1964.

CITATION: NAEC-ACEL 533. Philadelphia, Pa.; U.S. Naval Air Engineering Center, Air Crew Equipment Laboratory, 1965. (AD 626-332).

RATIONALE: There has been a lack of correspondence between aircrew station dimensions and the requirements for space to adequately accommodate the functioning crew member. This report dealt with anthropometric dimensions.

METHODOLOGY:

SAMPLE SIZE: The subjects numbered 1549, all males.

PROCEDURES: Ninety-six anthropometric measurements were made.

SIGNIFICANT RESULTS

Measurement	Mean	S.D.
Weight	171.40 lbs.	19.09 lbs.
Stature	69.94 in.	2.33 in.
Cervicale height	59.51 in.	2.18 in.
Sitting height	36.28 in.	1.25 in.
Eye height (sitting)	31.57 in.	1.18 in.
Knee height (sitting)	21.84 in	0.98 in.
Popliteal height (sitting)	17.31 in.	0.86 in.
Buttock-popliteal length	19.79 in.	0.99 in.
Buttock-knee length	24.09 in.	1.00 in.
Forearm-hand length	19.08 in.	0.75 in.
Functional reach	31.51 in.	1.42 in.
Hipbreadth (sitting)	14.49 in.	0.85 in.

CONCLUSIONS/RECOMMENDATIONS: N/A

CATEGORY: SEAT DESIGN

AUTHORS: Grandjean, E., Boni, A., & Kretzschmar, H.

TITLE: The development of a rest chair profile for healthy and notalgic people.

CITATION: Ergonomics, 1969, 12, 307-315.

RATIONALE: The present study was set up to develop an appropriate seat profile for a rest chair realizing that even a suitable seat profile would not result in a lasting correction of spinal deformity. The study was in three stages:

(1) Development of a seat profile for normal persons.
(2) Testing the normal seat profile on notalgic persons (persons experiencing backaches).
(3) Development of a rest chair causing the minimum discomfort to notalgic persons.

METHODOLOGY:

SAMPLE SIZE: In the first stage, 10 males sat for 150 minutes each. In the second stage, 36 males and 16 females were tested for 8 minutes each.

In the third stage, 17 females and 21 males, who had previously been treated for lumbar complaints were tested. All patients had roentgenological and clinical disc trouble between the 5th lumbar and the 1st sacral vertebrae. The mean age for males was 55 years and for females 59 years.

APPARATUS: A seat was used in which the backrest and seat could be of any inclination and the arm rests and seat any height. The seat surface and backrest consisted of frame members into which adjustable wooden slats were clamped. A foam rubber sheet of 6 cm. thickness was placed on the entire seat.

SIGNIFICANT RESULTS: The following dimensions were for healthy persons:

	reading	rest
Seat inclination:	23°-24°	25°- 20°
Backrest inclination:	101°-104°	105°-108°
Seat height:	39-40 cm.	37-38 cm.

For notalgic persons the following dimensions were found:

Back rest angle:	106°-107°
Seat inclination:	19°-21°
Seat depth (depressed):	47-51 cm.
Seat height (depressed):	38-42 cm.

CONCLUSIONS/RECOMMENDATIONS: The backrest must be provided with a frontal convex loin welt and, above the lumbar spine, a frontally slightly concave contour should be provided.

CATEGORY: SEAT DESIGN

AUTHORS: Grandjean, E., Hunting, W., Wotzka, G. & Scharer, R.

TITLE: An ergonomic investigation of multipurpose chairs.

CITATION: Human Factors, 1973, 15, 246-255.

RATIONALE: This paper investigated twelve types of chairs in terms of comfort.

METHODOLOGY:

SAMPLE SIZE: Twenty-five males and twenty-five females were used.

POPULATION CHARACTERISTICS: Ss had an average age of 22-24 years. Average heights were: females 166.5 cm. S.D. = 5.2 cm.; males 177.9 cm. S.D. = 6.3 cm. (These figures were about 5 cm. taller than the average of the Swiss population.)

PROCEDURES: Each chair was compared with every other chair in 66 paired comparisons. Ss could not see the chairs and sat in them for a few seconds. Later, Ss sat for 5 minutes in each of the 12 chairs at a table 74 cm. high. In addition, a questionnaire was completed.

SIGNIFICANT RESULTS: Seats with high backrests and profiles were found to be good in relation to the sensations in the back, nape of the neck, and lumbosacral region. Seats with a molded-seat surface were judged better for the buttocks than those with a flat surface. Seat surfaces which were flat in front produced fewer complaints about discomfort in the upper part of the thighs than those which curved upwards.

CONCLUSIONS/RECOMMENDATIONS:

(1) The backrest support is effective between 7 and 20 cm. above the lowest point of the seat surface. The height of the backrest should be at least 85 cm. above ground, so long as the highest point of the seat surface does not exceed 43 cm.
(2) Seat depth should not exceed 43 cm. so that the backrest can also be effective for small persons.
(3) Seat width should be 40 cm.
(4) A flat seat surface is recommended, ranging from 44 to 46 cm. A seat surface that slants up in front should have a height of 43 cm. at the highest point of the part supporting the thighs. On a seat surface that slants up in front, the surface supporting the thighs should break with a small curvature. For chairs which will be used for forward-inclined and reclined sitting, gently-molded seat surface which is flat in front under the thighs and slants upwards in the back under the buttocks is recommended.

CATEGORY: SEAT DESIGN

AUTHOR: Hawkins, F.

TITLE: Ergonomic aspects of crew seats in transport aircraft.

CITATION: Aerospace Medicine, 1974, 45 (2), 196-203.

RATIONALE: Evidence suggests that the incidence of low backpain among aircrewmen is abnormally high, thus the question of seat design may be of particular importance. The paper suggests some recommendation for crew seats.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Lumbar support: A needed feature is a variable lumbar support which can be easily adjusted by the individual. The optimum area of support is between the 2nd and 4th lumbar vertebrae.

(2) Thigh support: An adjustable thigh support, on the forward part of the seat should be provided.

(3) Seat pan contours: These should not create too much of a bucket effect in order to avoid discomfort from side pressures on the outside of the thigh joint.

(4) Seat cushions and fabrics: These should be firm but deformable to conform, to some extent, to the occupant's contours.

(5) Seat armrests: In order to prevent the shoulders from being forced up and to take a proper share of body weight, the armrests must be adjustable over an adequate range.

(6) Seat recline: Adequate recline capability must be available. If the seat is to be used for rest purposes, more than the minimum recline angle will be required (about 35°-40°).

(7) Seat bottom: The seat bottom should tilt up (about 7°).

CATEGORY: ANTHROPOMETRY

AUTHOR: Hertzberg, H. T. E.

TITLE: Some contributions of applied physical anthropology to human engineering.

CITATION: Annals of New York Academy of Sciences, 1955, 63, 616-629.

RATIONALE: This paper presents the results of three unpublished studies in applied physical anthropology. The first study summarizes the engineering use of the percentile curve as a tool to improve the sizing of work space, clothing, or personal equipment. The second outlines how the use of muscle-strength data can improve human safety and ease of machine operation. The third study attempts to answer the question, "What happens to the buttocks when you sit on them?"

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) It is incorrect to use the concept of the "average man" as the basis of design for human accommodation.

(2) Work spaces, to be efficient, should be constructed on the basis of design limits chosen according to the range of body size found in the user population (generally the 5th to 95th percentile).

(3) The use of the design limits or range of accommodation method is currently the best way to determine the muscle strength needed to operate controls in addition to the proper size of the controls.

(4) In considering the problem of reducing buttock fatigue, the author points out that the design limits approach is a viable one. He also describes the apparatus (an Air Force adaptation of the Pediscope) used to take data measurements on sitting pressure in various areas of the buttocks and the distance between the ischial tuberosities.

(5) The author emphasizes that the concept of averages is untenable as a basis for design, and that an intelligent choice of limits is the proper procedure in such widely different areas as workplace sizing, muscle-strength accommodation, or even the study of pain in one's seat.

CATEGORY: WORKPLACE DESIGN

AUTHOR: Hertzberg, H. T. E.

TITLE: Dynamic anthropometry of working positions.

CITATION: Human Factors, 1960, 2, 147-155.

RATIONALE: This paper provides a review of the principles and procedures of workplace design for engineers. It emphasizes that human body size, anthropometry, and muscle force capability, biomechanics, are both essential for the efficient sizing of equipment. The proper method of workplace design, the "design limits concept," is described and the fallacy of the "average man" concept is demonstrated.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) In planning a workspace for a seated man, the designer must know both the occupants' static dimensions (sitting height, buttock-knee length, knee height, arm reach, etc.) and his dynamic dimensions (the distances the man can move and the forces he can exert).

(2) The use of the "average man" as a solution for design problems is a fallacy, because no one is average in all dimensions.

(3) The only efficient method for design is the "design limits" concept, the anthropometric-statistical approach based on sound dimensions measured by standardized techniques on the population that will use the workspace.

(4) The "design limits" approach (also called the "range of accomodation" system) is very simple. Take relevant dimensions on an adequate sample of the user population, reduce the data statistically, and then choose from these data the dimensions for workspace according to the percentage of the population that the product is intended to accommodate.

(5) Design engineers should use the percentile curve over the range of the particular dimension they are interested in to assign cut-off points depending on how much of the population they wish to accommodate. All the design engineer need do is choose the design limits he wants from the percentile curve. Using such data, the engineer can determine the relative expense of accommodating the entire population as opposed to, say, 95 percent of the population.

(6) The designer should consider the environment as well as the man (i.e. heavy Artic clothing adds considerably to design dimensions).

(7) Design engineers should also consider limb position when deciding how much force must be exerted to operate a specific control.

(8) Workspace combining both static and dynamic data can be quite effective, yet they do not fully provide for the complexities of the human work needs. The final refinement will be possible when both space requirements and force output are measured simultaneously on the man.

CATEGORY: ANTHROPOMETRY

AUTHORS: Hertzberg, H.T.E., Daniels, G.S., & Churchill, E.

TITLE: Anthropometry of flying personnel - 1950.

CITATION: WADC Technical Report 52-321, Wright-Patterson Air Force Base, Ohio, Wright Air Development Center, September, 1954.

RATIONALE: The Anthropometric Survey Team of 1950 visited 14 Air Force bases and took 132 body measurements of more than 4,000 Air Force personnel in all flight categories.

METHODOLOGY:

SAMPLE SIZE: 4,000 male subjects were used.

POPULATION CHARACTERISTICS: Subjects were from 14 Air Force bases within the United States.

APPARATUS: Standard anthropometric instruments were supplemented by measuring - board techniques to satisfy the requirements of both speed and accuracy. Grid sheets graduated in centimeters and millimeters were tacked on the wall at a known distance from the corner of the room. Span and several arm lengths were taken by the grid sheets.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

Measurement	Mean	S.D.
Weight	163.66 lbs.	20.86 lbs.
Stature	175.53 cm.	6.19 cm.
Eye height	164.31 cm.	6.04 cm.
Shoulder height	143.51 cm.	5.80 cm.
Elbow height	110.48 cm.	4.50 cm.
Wrist height	85.15 cm.	3.92 cm.
Sitting height	91.28 cm.	3.27 cm.
Eye height (sitting)	79.94 cm.	3.22 cm.
Shoulder height (sitting)	59.07 cm.	2.89 cm.
Elbow rest height (sitting)	23.16 cm.	2.63 cm.
Thigh clearance height (sitting)	14.25 cm.	1.33 cm.
Knee height (sitting)	55.04 cm.	2.51 cm.
Popliteal height (sitting)	43.10 cm.	1.96 cm.
Buttock-Knee length	60.00 cm.	27.70 cm.
Forearm-hand length	47.91 cm.	2.07 cm.
Span (standing)	179.83 cm.	7.46 cm.
Arm reach from wall (standing)	87.86 cm.	4.18 cm.
Max. reach from wall (standing)	98.03 cm.	4.82 cm.

Measurement	Mean	S.D.
Functional reach (standing)	82.12 cm.	4.14 cm.
Elbow-to-elbow breadth	43.89 cm.	3.61 cm.
Hip breadth (sitting)	35.49 cm.	2.21 cm.

CATEGORY: ANTHROPOMETRY AND SEAT DESIGN

AUTHOR: Hooton, E.A.

TITLE: A Survey in Seating.

CITATION: Westport, Connecticut: Greenwood Press, Publishers, 1945.

RATIONALE: The project consisted of (1) taking 8 measurements on each individual of a group constituting a representative sample of the population of the U.S.; (2) reducing these measurements statistically; and (3) making certain recommendations, on the basis of the statistics, pertaining to the design of seats. The study was on railway travelers and includes 8 measurements relevant to the design of railway coach seats.

METHODOLOGY:

SAMPLE SIZE: 3, 867 persons.

POPULATION CHARACTERISTICS: Preponderance of persons from the New England, Middle Atlantic, and East North Central States. All economic levels were included and an equal number of males and females were selected.

PROCEDURES: Each individual was seated in the center of the chair with his buttocks in contact with the lower portion of the back of the chair and his shoulders in contact with the upper portion of the back of the chair.

APPARATUS: A special measuring chair manfactured by the Heywood-Wakefield Co. and, calibrated to an accuracy of 1/8 of an inch was used.

SIGNIFICANT RESULTS:

	Males			Females		
Measurement	5th	50th	95th	5th	50th	95th
Weight (lb.)	132.3	166.7	217.5	103.7	133.1	179.3
Stature (in.)	64.5	69.0	73.8	60.8	64.9	69.1
Buttock-Popliteal length (in.)	17.4	18.9	20.8	16.8	18.2	20.0
Popliteal height (in.)	17.6	19.0	20.6	16.7	18.1	19.5
1st-2nd cervical vertebrae (sitting) (in.)	26.6	28.6	30.6	24.9	26.7	28.6
Hip breadth (in.)	13.7	15.3	17.4	13.1	14.6	17.2
Shoulder breadth (in.)	16.4	17.6	19.2	14.4	15.5	17.6

CONCLUSIONS/RECOMMENDATIONS:

(1) Seat depth: 20 inches (based on Buttock-Popliteal length)
(2) Seat height: 16.9 inches (based on Popliteal height)

(3) Backrest height: 28. inches (based on region of 1st and 2nd cervical, sitting)
(4) Elbow (arm rest) height: 8.5 inches (based on length of the upper arm relative to the length of the torso)
(5) Backrest breadth: 22 inches (based on Shoulder breadth)
(6) Seat width: 21.3 inches (based on Hip breadth)

CATEGORY: REACH ENVELOPE

AUTHOR: Hugh-Jones, P.

TITLE: The effect of limb position in seated subjects on their ability to utilize the maximum contractile force of the limb muscles

CITATION: Journal of Physiology, 1947, 105, 332-344.

RATIONALE: The purpose of this study was originally for determining the placement of controls. Thus, the results compare pushing on a hand-grip with pulling for the same position. In general, the experiments were to ascertain the influence of limb position (arm and leg) on the force that can be exerted on an isometric control by a seated operator.

METHODOLOGY:

SAMPLE SIZE: Six male subjects were used in the first experiment to determine maximum push on a foot pedal. Subjects were between 21 and 36 years old and weighed 147 to 182 pounds. On all subsequent experiments, only two of the original six subjects were used. These subjects were 26 and 27 years old, weighed 172 and 168 pounds, and were 70 and 71 inches tall respectively. Their arm lengths were identical.

PROCEDURES: Joint angles were measured from bony points using a long-armed hinged protractor. Angles were measured both with the subject at rest and when maximum force was being exerted.

APPARATUS: The apparatus consisted of a metal seat with a flat, padded, and adjustable backrest, which supported both the subject's pelvis and back. The seat was mounted in a rigid wooden frame fixed to the wall and floor; two upright beams could be bolted securely in any of eight positions along the frame. An axle of 2 inch diameter steel tubing could be held so as to rotate freely in any of ten bearing-holes in the upright beams. A 300-lb. spring balance suspended from a ceiling beam, was attached by a chain to a hooded collar fixed on a steel rod. The latter was inserted through a hole in the axle at right angles to its length, and held there by two collars. Into any appropriate one of a series of holes in the axle was inserted either a pedal or a hand-lever and this was prevented from rotating by grooved collars. The pedal had a board freely slung under its crossbar. The hand-lever was a steel rod on which a wooden hand-grip could be clamped at any height above the axle.

SIGNIFICANT RESULTS:

(1) For the maximum push on a foot-pedal the optimal position was found to be thigh-angle of 15° and a knee-angle of 160°. This position produced a mean maximum push of 845 ± 35.4 lbs.

(2) For the maximum horizontal push on an isometric vertical hand lever, 29 inches from the center of the hand-grip to the seat back was found to be optimal for the four vertical planes in which it was measured (i.e., left shoulder (using left arm, mid-line (using right arm), right shoulder (using right arm) and outside shoulder 14 in. to right of mid-line (using right arm)).

(3) Maximum horizontal pull on a hand-lever was found to be at 35 inches from center of grip to seat back (full extension of the elbow). It was also found that for comparable positions horizontal pull is always less than push.

(4) Mean maximum pull on an isometric hand-lever with direction of pull at 45^{o} upwards was attained when the grip height was 6 inches below the seat level. This result was consistent for 17, 23, 29, and 35 inches between the hand-grip and the seat back.

CONCLUSIONS/RECOMMENDATIONS:

(1) It was shown that, in general, push or pull increases with extension of the acting joint until a maximum is reached just before the joint becomes straight.

(2) In general the increase shown in exertable push with increase in angle of the acting joint is explained by the fact that although the length of the acting muscle decreases, and consequently also the tension developed, the mechanical disadvantage against which the muscle acts also diminishes with joint extension and more than compensate for the effect of muscle length.

(3) For pushing on a control, against a seat backrest, the findings agree with the theory that the limb acts as a mechanical "toggle" between the control and the backrest. The toggle-action markedly increases the exertable push until a critical limiting angle is reached. This angle is 160^{o} for knee-extension and, approximately, 135^{o} for elbow-extension.

(4) For an iso-metric hand-lever, maximal push or pull is attainable when the elbow is extended up to the limiting angle (135^{o}), the hand-grip is about at elbow height for the seated subject, and the lever moves in a vertical plane which passes through the shoulder-joint.

(5) To exert pressure between an isometric hand-grip and a seat backrest is subjectively unpleasant, though the exertable push (because of toggle-action) is greater than the pull under comparable conditions. Because of the unpleasantness involved, the author concludes that conventional "pull-on" hand-brakes for vehicles are preferrable to a "push-on" variety.

CATEGORY: SEAT DESIGN

AUTHOR: Jones, J. C.

TITLE: Sensations in body parts as a measure of seat discomfort.

CITATION: Ergonomics, 1966, 9, 344.

RATIONALE: The purpose of the study was to determine if seats of varying degrees of comfort could reliably be discriminated using sensations in body parts as reported by subjects over time.

METHODOLOGY:

PROCEDURES: Experienced subjects recorded sensations in parts of their backs, buttocks, and thighs while sitting on various seats for up to 5 hours. Each subject assessed the sensation in each body part on a five-point scale of discomfort: 0 - no sensation; 1 - awareness; 2 - numbness; 3 - ache; 4 - pain. Discomfort levels were recorded at intervals of 5 minutes for seats that quickly became uncomfortable, and intervals of 15 minutes for seats that were tolerable for 5 hours or more.

SIGNIFICANT RESULTS:

(1) The subjects took several hours to reach level 4 (pain), when seated in conventional small car seats, whether the car was in motion or parked during the test.
(2) Subjects took about the same time to reach level 4 when seated in a room on an upright moulded plywood seat 17 in. high.
(3) When the plywood seat surface was mounted directly on the small car seats, the subjects all reached level 4 after about an hour an a half whether the car was in motion or parked during the test.

CONCLUSIONS/RECOMMENDATIONS:

(1) Initial results show that the method reliably discriminated between seats of very different degrees of comfort.
(2) It may be inferred that the effect of upholstery in a low seat is to make up for the sitter's inability to transfer pressure from one supported area to another by moving his legs and body.

CATEGORY: SEAT DESIGN

AUTHOR: Jones, J.C.

TITLE: Methods and results of seating research.

CITATION: Ergonomics, 1969, 12, 171-181.

RATIONALE: The purpose of this paper was to generate data to be used in the design of car seats, industrial seats, lecture theater seats, etc. and to develop research methods to be used by engineers and designers. Designers of the seat and workspace have first to identify identify what they believe to be the critical dimensions and then to design to accommodate a wide range of users. The initial settings of the apparatus are found by adjusting each dimension until a user of average size can carry out each of the task actions with no more difficulty or discomfort than the designers believe to be acceptable for the class of equipment that is being designed. The second part of the study provides a measure of seat discomfort. Trained testers record sensations in parts of the body at intervals during a journey.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The following results are of a fitting trial which shows the dimensions of a car interior designed to accommodate 98% of British males and females.

(1) Seat Height (Floor to front edge of compressed seat)	12 in.
(2) Seat Length (Junction of compressed squab and backrest to front edge of squab)	17 in.
(3) Seat angle (rearward declination)	7°
(4) Backrest angle	108°
(5) Interior height (floor to roof lining)	50.5 in.
(6) Footrest distance (Horizontal distance from front edge of seat to intersection of footrest and floor.)	10-20 in.
(7) Footrest angle	37.5°

The method of fitting trails is a modification of Morant's method of determining cockpit dimensions.

CATEGORY: SEAT DESIGN

AUTHORS: Karvonen, M.J., Koskela, A. & Noro, L.

TITLE: Preliminary report on the sitting postures of school children.

CITATION: Ergonomics, 1962, 5, 471-477.

RATIONALE: Relatively little attention has been given to the ergonomic problems of school work. Incorrect work habits adopted in an early phase can be detrimental to work efficiency and health. This paper summarized several points considered important in the designing of school equipment and a practical method of controlling how the pupils use school equipment.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: To induce people to adopt good working postures the first thing is to ensure that the chairs, tables and equipment that they use are correctly dimensioned and designed. For school furniture, the following recommendations were given.

(1) The desk and the chair should be separate. This makes it possible to adjust the distance between them according to the needs of each pupil.

(2) The table should be of such height that when the pupil sits in a free reading or writing position his eyes are 30 to 40 cm. from the table top. The pupil should be able to rest his forearms on the table without raising or hunching his shoulders. This means in practice a 25 to 30 cm. height difference between chair and table.

(3) The table top can be horizontal but a slight inclination is recommended.

(4) The chair seat should suit every pupil. This is possible if adjustable chairs or a series of chairs of different sizes are used.

(5) The chair should give good support to the lumbar spine. A lumbar support which is slightly convex in the vertical plane and concave in the horizontal one fits the shape of the back rest. The distance between the lower edge of the back rest and the seat should be 10 to 15 cm. The angle generally recommended between the back-rest and seat is approximately 105°, but in school chairs 90-100° is evidently best. The inclination of the backrest must be such that the person sitting can lean against it when slightly bent forward.

(6) The seat depth should be approximately 40 cm., depending on the pupil's size. To prevent sliding, the seat should slope slightly backwards. The front edge should be bent down or rounded so that it does not press on the under surface of the thigh.

(7) The chair height should be such that when the sitter's feet rest firmly on the floor the front edge of the seat does not press against the under surface of the thigh.

(8) The seat should be smooth and not moulded to conform to the buttocks. This enables shifting of position more freely.

(9) The space below the front edge of the seat should be free to permit changes in the position of the legs.
(10) The backrest should not reach up to the shoulder blades so that it restricts the movements of the upper limbs.
(11) There should be sufficient space between .e chair and the work table to shift position easily.
Observing the sitting postures pupils show that:
(1) a backrest is used for only half of the time.
(2) a forward inclined posture is the most popular; it is used over half of the time.
(3) There is no distinct regularity in the leg position.
(4) Both forearms are on the table for over half of the time.

CATEGORY: Seat Design

AUTHOR: Keegan, J.J.

TITLE: Alterations of the lumbar curve related to posture and seating.

CITATION: Journal of Bone and Joint Surgery, 1953, 35, 589-603.

RATIONALE: According to the paper, the site of most back symptoms arising from postural factors is in the lower lumbar spine, particularly in the fourth and fifth lumbar intervertebral discs which commonly degenerate with age under normal weight-bearing, sitting, and stooping strain. The paper presents recommendations for the dimensions of chairs with regard to the lumbar curve.

METHODOLOGY:

SAMPLE SIZE: Two males and 2 females.

POPULATION CHARACTERISTICS: Normal young persons with no history or roentgenographic evidence of abnormality.

PROCEDURES: Included showing the normal physiological alteration of the lumbar spine in various positions.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: A design, applicable to all seats regardless of their external form or special use, incorporating the basic requirements for a comfortable and protective seat, based on knowledge of the anatomical, physiological and pathological causes of low-back discomfort and pain is set forth.

(1) The most distinctive and important feature is the placement of the primary back support over the lower lumbar spine. The height of this support should be 9 in. and be slightly convex.
(2) An open or recessive space for the posteriorly projecting sacrum and buttocks should be provided. The open space should be about 4.5 in.
(3) There should be a minimum angle of 105° between the trunk and the thigh to help preserve the lumbar curve.
(4) The upper limit of the convex primary lower lumbar back support in the short backed "straight" chair should be well below the lower angles of the scapulae (i.e., about 13.5 in. from the seat).
(5) The shoulder support in high-backed chairs is secondary to lumbar support, placed at a minimum angle of 105° with the seat.
(6) Increase of the angle of the back of the seat is pivoted on a point in line with the hip joint.
(7) Maximum length of seat is 16 in.
(8) Height of seat is 16 in.
(9) Front border of seat should be curved downward.
(10) There should be a free space below the seat to allow for placement of the feet beneath the seat in rising and for relaxation

in sitting.

(11) Tilt or upward inclination of 5° should be provided for the seat pan.

CATEGORY: SEAT DESIGN

AUTHOR: Keegan, J.J.

TITLE: Evaluation and improvement of seats.

CITATION: Industrial Medicine and Surgery, 1952, 31, 137-148.

RATIONALE: Recent medical knowledge of the cause of most postural low back discomfort and pain in degenerated lower lumbar intervertebral discs has permitted better analysis of the seating problem. The paper presents three misconceptions concerning seating: (1) that the proper sitting position is at a right angle between trunk and thighs; (2) that the chief back support should be at the shoulders; and (3) that the seat should support the thighs. This has led to seats with high, vertically straight, near right-angled backs that flatten the lumbar curve, and to excessively long seats which interfere with positioning of the legs.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) The most important requirement for a correct seat is placement of the primary or chief back support over the lower lumbar spine where most postural back trouble is located. Shoulder support is necessary only in resting seats. Support must be vertically curved.
(2) The minimum angle of shoulder support (i.e., angle between line of the shoulders and the seat) should be 105°.
(3) Length of seat should be 16 in.
(4) Height of seat should be 16 in. Seats need to be higher for work over the standard 30 in. high desk or table in order to maintain the needed visual distance of 16 inches to which reading glasses are adjusted. In these cases, the seat height should be 18 in., but the seat length should be 14 in.
(5) Tilt of seat should be 5° upward in front.
(6) The front border of the seat pan should be rounded.

In addition, 31 seats are evaluated on the preceding points. The seats were classified according to their location and use as follows: office, home, public, transportation, and machinery seats. Ways to improve the 31 seats are also included in the paper.

CATEGORY: REACH ENVELOPE

AUTHORS: Kennedy, K. W.

TITLE: Reach Capability of the USAF Population: Phase I -- The Outer Boundaries of Grasping-Reach Envelopes for the Shirtsleeve, Seated Operator

CITATION: Wright-Patterson Air Force Base, Ohio, Aerospace Medical Research Laboratory, 1964.

RATIONALE: The purpose of this report was to describe the outer boundaries of the minimum, 5th, 50th, and 95th percentile grasping-reach envelopes for the shirtsleeved, seated operator and to discuss the factors influencing his reach capability. The term grasping-reach denotes grasp between the thumb and the second phalanx (middle segment) of the forefinger.

METHODOLOGY:

Sample Size: Twenty male subjects were used.

Clothing: Each subject wore a shortsleeved shirt.

Procedures: (A) The subject centered himself on the seat by seeing equal amounts of footrest space between the center brace and leg on each side of the seat. The subject would press his back firmly against the backrest with his torso in the center of the seat. The experimenter would review and stress the importance of the exact position of each reach. Each subject was allowed to practice orienting himself. Each trial lasted an hour.

(B) The measurements taken included: seat in 0^{0} position; reach information throughout a vertical plane through the center of the arch (PO) forward is 0^{o}; rear -180^{o}); from seat 15^{o} right; vertical plane left 15^{o} to right 165^{o} at 15^{o} intervals to seat 165^{o} right; left 165^{o} to right 15^{o} plane. Repeatability tests were given to insure confidence of measurements.

(C) Data was handled as seat 15^{o} to the right, reach distances recorded as vertical plane of reach had rotated 15^{o} to subject's left (left 15^{o} right 165^{o} plane).

(D) Data was transformed so that the vertical planes were converted to represent horizontal sections.

(E) The angular reach capability and linear reach capability were then determined.

Apparatus: The AMRL Research Measuring Device was employed which was a rotatable seat mounted on a platform beneath an arch, the seat's centerline (vertical) lies in the arch's plane. The arch has friction-held measuring staves at 15^{o} intervals, calibrated to indicate distance from center of arch to midpoint of a knob at the inside end of stave. The center of the arch (PO) was the vertical axis the seat rotation passes through; the SRP is 10 in. to the left and 23 in. below PO. The maximum grasping reach measurable was 38 in. Casters facilitated chair rotation on a track of steel. Seat orientation was measured on a circular 15^{o} interval scale on the platform around the pivot of the chair. A large button switch on back of the chair 18 in. above SRP and 3 in. to the right of the seat back midline connected to a light insured proper shoulder position.

SIGNIFICANT RESULTS:

(1) Contours for each 5 in. level through the outer boundaries of the minimum, 5th, 50th, and 95th percentile grasping-reach envelopes were obtained. All contours between 5 in. below SRP and 30 in. above SRP were incomplete since arm movements were inhibited at times by the sides and rear of the chair.

(2) Ranking of reach capability of the subjects in four major sections of the envelope were obtained.

(3) Mean values of various anthropometric dimensions for the 5 longest reaches and 5 shortest reaches were given.

(4) A correlation matrix between anthropometric dimensions and measures of reach capability was presented. There were several high correlations between anthropometric dimensions and reach capability: (a) functional reach plus acromial height with overhead reach, (b) functional reach plus acromial height with downward reach, (c) functional reach plus biacromial diameter with lateral reach, (d) functional reach with lateral reach. Subjects with greater shoulder mobility have greater angular reach to right rear.

CONCLUSIONS/RECOMMENDATIONS:

(1) The two most important influences on size and shape of grasping-reach envelope were: (a) the distance from center of shoulder rotation to the tip of the thumb, and (b) characteristics of motion of the shoulder joints. Other factors include : (c) acromial heighr (sitting), (d) one-half the distance between right and left glenohumeral joint centers, and (e) lengths of arm and leg segments.

(2) Influences contributing to variability in arm reach capability include (a) correlative dimensions and (b) one cannot vary arm reach capability without producing a variation of the envelope.

(3) Because of the high tendency for body dimensions to restrict reach capability the "5th percentile reach envelope" is not necessairly true for a 5th percentile man.

CATEGORY: CONSOLE DESIGN

AUTHORS: Kennedy, K. W., and Bates, Jr. C.

TITLE: Development of Design Standards for Ground Support Consoles.

CITATION: Wright-Patterson Air Force Base, Ohio: Aeroapace Medical Research Laboratories, 1965, AMRL-TR-65-163.

RATIONALE: Ground console designs for possible standardization in future systems were described in detail. All of the ground console designs were derived from a basic sit-stand configuration and will accommodate approximately 95% of the USAF male population and approximately 60% of the USAF female population. Five console types were recognized based on the posture best suited for monitoring and whether or not the operator is required to have horizontal vision over the top of and beyound the console. The five console types were (1) alternate sitting or standing, (2) sitting with vision over the top, (3) sitting without vision over the top, (4) standing with vision over the top, and (5) standing without vision over the top.

METHODOLOGY

PROCEDURES: Each console profile was developed from anthropometric data (Hertzberg, Daniels, and Churchill, 1954) that described the all male USAF population. Since visual and arm-reach capabilities and limitations are so important in console design, they were given preferential consideration. The first point of reference was the eye position and then the reference point for reach accommodation was then approximated relative to the eye reference point.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: For the sit console type, the following dimensions are set forth:

Minimum knee clearance - 18 in.
Seat to heel catch on floor - 18 in.
Minimum seat adjustability - 4 in.
Minimum thigh clearance at
midpoint of seat adjustability -6.5 in

For all five types of consoles, the following dimensions are recommended:

Minimum pencil-shelf depth - 4 in.
Minimum writing surface depth - 16 in.
including pencil shelf
Console panel angle from - 15°
Vertical

The maximum console height from standing surface should be with respect to the type of console:

Sit-stand - 62 in.
Sit with vision over the top - 47.5 to 58 in.
This dimension must never be more than
29.5 in. greater than the seat height at
the midpoint of the seat adjustability.
Sit without vision over the top - 51.5 to 62 in.
This dimension must never be more than
33.5 in. greater than the seat height at

midpoint of the seat adjustability.
Stand with vision over the top - 62 in.
Stand without vision over the top - 72 in.

The writing surface height from the standing position should be 36 in. for all console types, except the sit only types in which the writing surface height should be 25.5 to 36 in.

The maximum console panel breadth should be 36 in. for consoles without vision over the top, and 44 in. for consoles with vision over the top.

The suggested vertical dimension of panel, including the sills should be as follows:

Sit-stand - 26 in.
Sit with vision over the top - 22 in.
Sit without vision over the top - 26 in.
Stand with vision over the top - 26 in.
Stand without vision over the top - 36 in.

For the sit-type consoles, the Seat Reference Point should lie about 8.25 in. in front of and 6.5 in. below the underside of the writing leaf when the seat is at the midpoint of its adjustability. The back of the seat should slope away from the front of the console at about 13° from the vertical. The seat-back should provide support for the operator's back at least from about the second lumbar vertebra to the 10th thoracic vertebra. The arm rest should not interfere with the use of the writing leaf. The arm rests should not extend more than 8.25 in. forward from the Seat Reference Point, and should be 9 in. above the seat. If the seat height is higher than 18 in., a heel-catch should be provided at a distance of 18 in. below the seat.

CATEGORY: MODELS, WORKPLACES

AUTHOR: Kilpatrick, K. E.

TITLE: A biokinematic model for workplace design.

CITATION: Human Factors, 1972, 14, 237-247.

RATIONALE: The paper reported the use of a computerized biokinematic model of the operator in the design of workplaces. The model simulates the spatial relationships between the operator and the workplace for a given workplace configuration and task sequence before the design is mocked up or committed to hardware.

METHODOLOGY:

PROCEDURES: Steps in the model development were as follows:

(1) Describe the operator as a set of joint centers and connecting links.
  - (a) A link is a non-deformable connection.
  - (b) A joint center is the mean of the joint centers at a a joint or the proximal end of a link at the best center of rotation for the distal end.

(2) Define a movement - excursion envelope at each joint center. The definite data is scarce so most envelopes are estimated mathematically.

(3) Develop a programmable logic which would provide the prediction of the joint centers.

SIGNIFICANT RESULTS:

The limitations of the model are as follows:

(1) Limited to predicting the body configuration for a seated operator reaching to positions that do not require him to exceed normal active ranges of joint movement.

(2) The operator is assumed to be able to position his body links freely in space.

(3) Effects of sex, age, encumberances, and disabilities are not incorporated.

(4) Limited validation.

The validation phase compared in three ways predictions and actual positions with five subjects and 35 positions each. The mean miss-distance was: 2.48 in. at the wrist, 5 in. at the elbow, 4.7 in. at the shoulder, 5 in. at the clavicle, and 4.7 in. at the T-4.

Applications of the model:

(1) To determine the reach feasibility of a workplace configuration-task sequence combination.

(2) To determine if physical interference exists between the operator and workplace during a task.

(3) Task-time predictions as a measure of design effectiveness.

CATEGORY: SEAT DESIGN

AUTHORS: Kirk, N.S., Wards, J.S., Asprey, E., Baker, E. & Peacock, B.

TITLE: Discrimination of chair seat heights.

CITATION: *Ergonomics*, 1969, 12, 403-413.

RATIONALE: British Standards states that the height of the front edge of the seat above the floor for non-adjustable office chairs should be 43.18 cm. (17 in.). This recommendation is based primarily on physiological and anatomical considerations; subjective comfort has been ignored. There is a need for experiments in which the seat height is systematically varied and measures of comfort are obtained at each seat height. Before this can be done, there is no *a priori* way of knowing what size of deviation it would be most effective to examine. This study was conducted to see how well subjects could discriminate between a standard seat (set at height of 43.18 cm.) and the height varied in 0.64 cm. steps (between 40.64 and 45.72 cm.).

METHODOLOGY

SAMPLE SIZE: Fifteen males and 15 females were used.

POPULATION CHARACTERISTICS: The female Ss were representative of British women between the ages of 18 and 40 years. The male Ss were taller than British men between the ages of 18 and 40, but were equivalent to other university students.

PROCEDURES: The method of constant stimuli was used. Nine comparison seats were used. Ss were blindfolded and not permitted to touch the seats.

APPARATUS: The seats were of a flat wooden surface 40.64 cm. in width and 38.10 cm. in depth with a slope of 5° from front to back. The standard height was 43.18 cm. and the range was from 40.64 to 45.72 cm. in 0.64 cm. intervals.

SIGNIFICANT RESULTS: The mean Differential Limen for males was 0.84 cm. and for females was 0.64 cm. The mean Point of Subjective Equality for males was 43.08 cm. and for females was 43.05 cm. No relation was found between these two measures and anthropometric dimensions.

CONCLUSIONS/RECOMMENDATIONS: It is highly probable that any seat which departs by about 2.5 cm. or more from the recognized B.S.I.'s recommendation of 43.18 cm. will be perceived as different by everyone everytime provided that (1) subjects are asked to make a comparative judgment, and (2) the temporal interval between presentation of seats is short.

CATEGORY: SEAT DESIGN

AUTHORS: Kocker, A.L. & Frey, A.

TITLE: Seating heights and spacing.

CITATION: Architectural Record, 1932, 71, 261-269.

RATIONALE: The paper was concerned with individual seat requirements and architectural arrangements for school, theatre, and stadium seating.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The paper mainly deals with seating arrangements in various seating capacity frameworks such as school, theatre and stadium. The paper sets forth the following recommendations:

(1) The seat height should be 18 in.
(2) The depth of the seat should be 16 in.
(3) The seat width should be approximately 17 in.
(4) The backrest should be convex for lumbar support.

CATEGORY: REACH ENVELOPE

AUTHOR: Konz, S. A., Jeans, C. E., & Rathore, R. S.

TITLE: Arm motions in the horizontal plane.

CITATION: AIIE Transactions, 1969, 1, 359-370.

RATIONALE: The purpose of thi. study was to re-evaluate the two principles of motion economy.

METHODOLOGY:

SAMPLE SIZE: Eighteen females were used in the first experiment. Seven females were used in the second experiment.

PROCEDURES: Subjects moved a 2 lb. weight in each hand between two specified points.

(1) Hands moved simultaneously and symmetrically.
(2) hands moved simultaneously and nonsymmetrically.
(3) Hands moved alternating and symmetrically.

A force platform measured the combined static and dynamic forces Physiological cost was defined as the amount of force exerted for a given time period. Subjects were paced by a metronome at 66 clicks per minute. There were 3 conditions, 6 sequences with three subjects per sequence.

In the second experiment, subjects made repetitive motions between outer targets and inner targets.

(1) At angles of 0. 30. 60, 90, 120, 150, and 180.
(2) Worktable set 1 in. below standing elbow height of subject.
(3) Single hand movements made at 9 and 16 inches distances.
(4) Simultaneous hand motions made at above angles with hand spread at same angles.
(5) A formal set of instructions and a practice session given.
(6) Each trial was 18 sec.
(7) Speed and accuracy was converted to bits of information processed according to Fitts.

SIGNIFICANT RESULTS:

Experiment 1:

(1) Condition 1 is better than condition 3 but condition 2 was better than condition 1 which does not agree with literature.
(2) Inward motions are better than outward motions, another disagreement.

Experiment 2:

(1) For single hand motion- right superior to left in speed and accuracy accuracy and speed were not compatible at maximums.
(2) Simultaneous hand motion - less spread the better the performance; spread more important than symmetry but symmetry better than nonsymmetry.
(3) The limiting factor in hand-arm motions is the ability to nerves and muscles to carry out orders.

CONCLUSIONS/RECOMMENDATIONS:

The two principles of motion economy were evaluated and subsequently changed to five principles:

(1) For one hand motions, movements which pivot about the elbow are preferred to pivots around the shoulder.

(2) For one hand motions, movements with the preferred hand are more desirable than with the nonpreferred hand.

(3) Two hand motions are preferred to one hand motions.

(4) For two hand motions, simultaneous motions are preferred to alternating motions.

(5) For two hand simultaneous motions, a pattern which minimizes eye fixations is preferred.

CATEGORY: WORKPLACE DESIGN

AUTHOR: Koskela, A.

TITLE: Ergonomics applied to office work.

CITATION: *Ergonomics*, 1962, 5, 263-264.

RATIONALE: Studies made on the working place itself and the practical applications of the results differ much from studies made in the laboratory. This paper dealt with the working conditions of 300 office workers with some observations by the author. The reason for this investigation was the common complaints of pains and aches in back, neck, shoulders and arms among the office workers.

METHODOLOGY:

PROCEDURES: The workers were interviewed and observed. Attention was paid toward the dimensions and design of desks and chairs, towards the posture and movements of the worker and the muscular pains. Secondly, attention was directed to lighting, ventilation, etc.

SIGNIFICANT RESULTS: The following weaknesses were noticed for secretaries who had a large writing desk and a narrow typewriter desk of a standard type with one leg and of a standard height.

(1) The typewriter desk was very often too high.
(2) The too narrow typewriter desk resulted in a situation where the elbow closest to the desk did not have enough space to move freely and the worker had to lean away from the desk.
(3) The one-legged desk did not prevent the typewriter from rocking and moving.
(4) At times there was lack of room on the desks.

CONCLUSIONS/RECOMMENDATIONS: The following alterations were made on the working place of these secretaries:

(1) The legs of the typewriter desk were made adjustable in order to fit the height according to each secretary.
(2) In order to obtain free space for the elbow and to avoid sitting in a leaning position, the typewriter desk was made longer.
(3) For secretaries who had more than one telephone and a dictaphone, working places in the form of a U were constructed.

CATEGORY: SEAT DESIGN, CONSOLE DESIGN, AND WORKPLACE DESIGN

AUTHOR: Kroemer, K.H.E.

TITLE: Seating in plant and office.

CITATION: *American Industrial Hygiene Association Journal*, 1971, *32*, 633-652.

RATIONALE: Improper design of seating (or non-consideration of available design data) may lead to improper posture of the worker, thus increasing fatigue and discomfort at the work station. The paper discusses the biomechanical, anthropometric, and physiological data and findings. The paper presents recommended dimensions for work stations (i.e., office equipment, consoles, work benches, and machine stands), as well as for seat design.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The trunk should be naturally upright and relaxed; severe bending of the spinal column should be avoided. The choice of and ability to change posture should be available to the seated operator. Body weight transmission to the seat should be through the buttocks, not through the thighs. A backrest should be provided. The paper recommends the following shapes and dimensions for seat design:

(1) Seat height: The height is correct if thighs are horizontal, lower legs vertical and feet flat on the floor. The seat height should be adjustable between 40 and 50 cm. above the floor or foot rest pan.
(2) Seat width: The seat width should be approximately 40 cm.
(3) Seat depth: The seat depth should be approximately 40 cm.
(4) Seat pan slope: The slope should be adjustable $\pm 6^{\circ}$ about the horizontal.
(5) Seat pan shape: Pronounced shaping should be avoided as it tends to limit variations of sitting posture. The seat pan should be upholstered stiffly, giving not more than 2.5 cm. The front edge should be rounded with a radius of at least 2.5 cm.
(6) Backrest: For lumbar support only, the backrest should be approximately 32 x 18 cm. The backrest should be slightly concave toward the sitting person in the top view, and slightly convex in the side view. It should be tiltable $\pm 15^{\circ}$ against the vertical about a horizontal axis in the lumbar region. The lower edge of the support should be between 8 and 15 cm. above the seat.
For a full-sized backrest, the 12 cm. over the seat pan

should be open or recessed. The backrest should be at least 38 cm. wide. The most forward protruding part should be 18 to 20 cm. above the seat pan. The backrest may rise up to shoulder height, 50 to 60 cm. over the seat.

The manual work area and leg room recommendations for the seated operator include the following:

(1) Leg Room Width: Minimum 60 cm. Desirable 65 cm.
(2) Leg Room Depth: Minimum 30 cm. Desirable 65 cm.
(3) Leg Room Height: Minimum 60 cm. Desirable 75 cm.
(4) Foot Room Depth: 65 cm.
(5) Foot Room Width: Minimum 40 cm. Desirable 65 cm.
(6) Foot Room Height: 25 cm.
(7) Horizontal distance of work area from front edge: 15-30 cm.
(8) Height of top surface: Minimum 65 cm.
(9) Height of work area: 65 - 100 cm.

The recommendations can only be considered as guidelines which, generally, will help to avoid blatant mistakes and help put the designer on the right track.

CATEGORY: SEAT DESIGN, WORKPLACE DESIGN

AUTHORS: Kroemer, K.H.E., & Robinette, J. C.

TITLE: Ergonomics in the Design of Office Furniture: A Review of European Literature.

CITATION: Wright-Patterson Air Force Base, Ohio. Aerospace Medical Research Laboratories, 1968. AMRL-TR-68-80. Also published in Industrial Medicine and Surgery, 1969, 38, 115-125.

RATIONALE: The body posture of sedentary workers, especially in offices, and of school children has long been a concern of orthopedists and physiologists. Complaints about lower back pains are widespread among people who commonly work in the sitting position. This report reviewed the European literature relevant to body posture of sitting persons and to the chairs, desks, and tables they use.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The following general recommendations for the sitting postures, hence for furniture design, were abstracted from the literature:

(1) The trunk, including neck and shoulders, should be in a natural, upright, but relaxed posture. The spinal column should not be bent severely and, especially, kyphosis of the lumbar spine should be avoided.

(2) The seated person must be able to choose and change his body posture. No body posture can be maintained indefinitely, as even the most comfortable position becomes unbearable after some time. Enforced posture generally occurs if the head (eyes) or the hands or feet (controls) must be kept in certain positions, or if the seat surface is small or distinctly shaped.

(3) The body weight should be transmitted to the seat surface mainly through the buttocks. Weight transfer through the thighs should be avoided. The surface of the seat should have flat upholstery in order to distribute the pressure.

(4) A back rest should be provided so that the sitting person can lean back temporarily at least. This enables him to relieve some weight from the spinal column.

(5) The height of the seat should be adjusted so that both feet can be placed firmly on the floor while the thighs are horizontal. The angle between thighs and trunk should be greater than 90 degrees.

(6) Chair and desk (or table, stand, etc.) should be treated as a unit. The height of the desk should be derived from the height of the seat surface.

The report emphasizes the following dimensions:

(1) Seat surface height - The height of the seat should be slightly less than the distance from the floor to the popliteal area of the seated individual. The seat must be adjustable so that each person can choose the proper height.

(2) Seat surface shape - Distinctive shapes of the seat surface limit the number of possible variations of the sitting posture. A generally horizontal seat having a slightly concave curvature in the center appears to be most suitable. This concavity facilitates sitting in the center of the seat, prevents the buttocks from slipping off, and still permits various postures. A flat, stiff upholstery that gives way only a few centimeters under the weight of the body is frequently recommended.

(3) Seat surface breadth - The seat may be as broad as reasonable.

(4) Seat surface length - The seat length must not be excessive. If the seat is too long an individual tends to sit on only the front part to avoid pressure on his thighs near the knees. Consequently, he will not use the backrest.

(5) Backrest - Just above the seat surface, the backrest should either have an open space or recede so that the sacrum can be pushed back and lumbar contact made with the rest. If free mobility of the shoulders and arms is necessary, only the lower part of the back can contact the backrest. A lumbar back support can be provided by a small back rest, the upper edge of which is not more than about 35 cm. and the lower edge approximately 12 cm. above the seat surface.

(6) Surface of the desk should be about at elbow height.

CATEGORY: SEAT DESIGN, CONSOLE DESIGN, AND WORKPLACE DESIGN

AUTHORS: Kubokawa, C. & Woodson, W.

TITLE: Databook for Human Factors Engineers Vol I: Human Engineering Data.

CITATION: Man Factors, Inc., San Diego, Cal., Nov. 1969, (NASA-CR-114271).

RATIONALE: The paper relates typical human engineering data useful in determining optimum design characteristics of equipment operated or maintained by human operators and/or maintenance personnel.

METHODOLOGY:

PROCEDURES: Equipment design dimensions were based on the following anthropometric surveys. Hertzberg (1950), U.S. Army HEL-STD-S-3-65, and U.S. Army QM-TR-EP-150.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

Chair Dimensions	Fixed	Adjust
(1) Arm rests		
(a) length	10 in.	± 2 in.
(b) width	2 in.	
(c) height	8.5 in.	± 2.5 in.
(d) separation	18 in.	
(2) Seat		
(a) width	16 in.	
(b) height	18 in.	± 2 in.
(c) depth	16 in.	
(3) Backrest		
(a) space	6 in.	± 2 in.
(b) height	15 in.	
(c) maximum curve	4 in.	
(d) width	16 in.	
(4) Footrests		
(a) from center	7 in.	
(b) width	6 in.	
(c) length	10 in.	
(5) Minimum clearance requirements		
(a) kneehole depth	18 in.	
(b) kneehole width	20 in.	
(c) kneehole height	26 in.	
(d) desk to wall	32 in.	
(e) lateral work clearance		
(1) shoulders	23 in.	
(2) elbows	25 in.	
(3) best overall	40 in.	

(6) Desk or work surface dimensions	Min	Best
(a) height	29 in.	30 in.
(b) width		
(1) elbow rest alone	4 in.	8 in.
(2) writing surface	12 in.	16 in.
(3) desk work area		36 in.
(c) length	30 in.	

CATEGORY: SEAT DESIGN AND CONSOLE DESIGN

AUTHOR: Langdon, F. J.

TITLE: The design of card punches and the seating of operators.

CITATION: Ergonomics, 1965, 8, 61-68.

RATIONALE: Comfortable seating of machine operators depends upon chairs of anthropometric design, capable of adjustment, but also on the shape and dimensions of the equipment itself. This study provided data on the design of card punches and on the seating arrangements in the card punch room. User assessment of comfort is also presented.

METHODOLOGY

SAMPLE SIZE: One hundred forty-two female punch operators were used.

POPULATION CHARACTERISTICS: The subjects worked in 7 locations. The ages of the subjects ranged from 16 to 45, although 90% of the samples were between 16 to 25. The mean height of the subjects was 64 in. (unshod).

PROCEDURES: Several measurements were taken (e.g. seat height, height of keyboard, etc.), along with responses to a questionnaire.

APPARATUS: The chairs' heights were adjustable between 15 to 24 in. The height and rake of the backrest were also adjustable.

SIGNIFICANT RESULTS:
(1) The mean height of the leading edge of the seat was 19.23 in. This was higher than a conventional office chair (18 in.) and a chair conforming to British Standard 3044 (17 in.).
(2) There does not appear to be any relation between the height of the operator and the height of the seat, as well as the height of the seat and type of shoe worn.
(3) The seat height was highly correlated with the height of the keyboard.
(4) The height of the elbow and the height of the keyboard were highly correlated.

CONCLUSIONS/RECOMMENDATIONS: The factor which determines the height to which the seat was set was the height of the keyboard. The reason why the seats of the chairs were so far from the floor was that the keyboards of the machines were too high for the operator to be able to depress the keys easily, while sitting on a chair with the seat low enough for her feet to rest upon the ground. It would seem, in practice that the majority of operators rate the need to dominate the keyboard above the desire for a comfortable posture.

CATEGORY: WORKPLACE DESIGN AND REACH ENVELOPE

AUTHORS: Laubach, L. L. and Alexander, M.

TITLE: Arm-reach capability of USAF pilots as affected by personal protective equipment.

CITATION: Aviation, Space, and Environmental Medicine, 197?, , 377-386.

RATIONALE: To determine the effects of protective equipment of pilots on arm-reach envelope, pilots were measured on an arm-reach apparatus under two conditions: maximum protective gear assembly with locked inertial-reel shoulder harness and shirtsleeve assembly with unlocked inertial-reel harness.

METHODOLOGY:

SAMPLE SIZE: Thirty-two pilots, selected to approximate USAF age, height, and weight tables for flying personnel, were used.

CLOTHING: Subjects wore maximum flying protective assembly versus shirtsleeve assembly.

PROCEDURES: The reach envelope of each pilot was measured under two experimental conditions: (1) Shirtsleeved with the inertial reel unlocked and (2) Complete winter flying assembly with inertial reel locked. Procedure was as follows: The subject was strapped in the seat with lap belts and shoulder harnesses. The vertical knob panel was preset at an angle chosen randomly. With the appropriate arm and hand, the subject reached first for the knob located 15 cm. above the deck. After pushing the rod to arm's length, the subject turned the knob to the right a quarter turn using a thumb/forefinger grip. After the distance was recorded, he proceeded to the next knob 15 cm. higher and continued the procedure until all 10 knobs had been pushed and turned. The vertical knob panel was then moved to a different angular position and the procedure repeated until all seven angular and two crossover reach positions were completed.

APPARATUS: The apparatus consisted of a seat adjustable ±6.35 cm. along a 13° back angle from the neutral seat reference point (SRP). The seat was equipped with an adjustable shoulder restraint harness and lap belts. An overhead boom was mounted above the seat and anchored to the frame of the measuring apparatus. It rotated horizontally about an axis through the SRP through an arc of 180° forward of the seat (90° to the right and 90° to the left) with stops at 30° intervals. Located on the horizontal arm of the overhead boom was a measuring scale with its origin directly vertical to the SRP. A vertical rod was attached to the horizontal arm of the overhead boom and was capable of fore-aft movement. Standard control knobs mounted on the vertical rod were spaced 15 cm. apart beginning 15 cm above the deck and extending to a height of 152 cm. above it.

SIGNIFICANT RESULTS: This article contains numberous tables and figures depicting the arm-reach capability of pilots in both shirt-sleeve and full flying gear. Reach data is given for the following 9 angles: 90°, 60°, 30°, -30° (for both left and right arms) and for 0° (preferred hand); and the following heights above the deck: 15 cm., 31 cm., 46 cm., 61 cm., 76 cm., 91 cm., 107 cm., 122 cm., 137 cm., and 152 cm. This yields a total of 180 data points for each subject. The tables give the following information for both arms of the shirt-sleeved, unrestrained and flying gear, restrained conditions: 5th percentile, mean, standard deviation, and the 95th percentile. In addition, figures depicting the reach envelopes for various heights are included.

CONCLUSIONS/RECOMMENDATIONS: The results of this study lead the authors to the following conclusions:

(1) There are significant statistical and practical differences in arm-reach capability of pilots between the shirt-sleeved and the maximum flying assembly conditions.

(2) For all practical purposes, the differences between the right and left arm reaches throughout most of the spatial envelope are negligible.

(3) For the arm-reach locations investigated in this study, the angular positions of 90° and 60° at a height above the deck from 46-91 cm. would seem to be optimal in terms of absolute arm reach.

CATEGORY: SEAT DESIGN

AUTHOR: Le Carpentier, E.F.

TITLE: Easy chair dimensions for comfort--A subject approach.

CITATION: *Ergonomics*, 1969, 12, 328-337.

RATIONALE: The present study was concerned with the physical dimensions of the chair only. The objectives were to determine the optimum values for the dimensions of easy chairs for the user population and to arrive at figures which will help designers of easy chairs to achieve a better fit for the majority of users.

METHODOLOGY:

SAMPLE SIZE: Twenty Ss were used.

POPULATION CHARACTERISTICS: Ten males and ten females were selected on the basis of stature and age so that the average stature of the group was close to that of the British adult population and half the men and women were younger than 40. Anthropometric measurements were: Popliteal height--mean=16.3 in., S.D.=1.0 in.; Knee to buttock length--mean=18.4 in., S.D.=1.4 in.; Seated elbow height--mean=8.7 in., S.D.=1.1 in.

PROCEDURES: Ss sat in the chair for periods of up to three hours, and at intervals adjusted each dimension to the level which by his judgment matched a written criterion of comfort supplied by the E. The S's task was either to read or watch television.

APPARATUS: A specially constructed chair was used. Four chair dimensions (height of seat, seat depth, seat tilt, and seat to backrest angle) were independently adjusted by the S operating switches built into the arm of the chair, which actuated four reversible electric motors built into the chair. Armrests and headrests could be adjusted manually by the E. The seats and armrests were foam padded. The headrest measured 15 x 8 in.; seat and backrest width was 21 in.; armrest separation was 22 in., height of the top of backrest above the unloaded seat was 21 in.

SIGNIFICANT RESULT: The Ss, on the average, preferred the seat 0.5 in. deeper than their "back of knee-buttock" length. The Ss, on the average, preferred the front of the seat 1.5 in. lower than their "floor to underside of thigh" length. A higher seat front was preferred by the women than by the men

CONCLUSIONS/RECOMMENDATIONS: Men preferred a horizontal or lounging posture while the women preferred to sit more upright and with a steeper seat tilt angle. The absence of correlation between the preferred dimensions and the corresponding anthropometric measurements for seat height and seat depth suggests that the significant negative correlation between preferred seat height and preferred seat depth was due to personal choice factors other than the simple anthropometric ones.

Dimensional values recommended for easy chairs:

		Males	Females
(1)	Height of seat front (inches)	15	16.5
(2)	Seat depth (inches)	18.5	18.5
(3)	Seat tilt angle (degrees)	9.0	12.0
(4)	Seat to backrest angle (degrees)	113	105
(5)	Backrest rake angle (degrees)	121.5	117.0
(6)	Armrest height above seat (inches)	6.5	6.5
(7)	Headrest center in front of backrest plane (inches)	2.5	2.5
(8)	Headrest angle forward from backrest plane (degrees)	8	8

CATEGORY: WORKPLACE DESIGN

AUTHORS: Less, M., Eickelberg, W.W.B., & Palgi, S.

TITLE: Effects of work surface angles on productive efficiency of females on a simple manual task.

CITATION: Perceptual and Motor Skills, 1973, 36, 431-436.

RATIONALE: The paper investigated the effects of work surface angles on production efficiency of a simple manual task by females.

METHODOLOGY:

SAMPLE SIZE: Twelve female college students were used.

POPULATION CHARACTERISTICS: The subjects ranged in age from 19 to 21, in weight from 112 to 132 lbs., and in height from 5 ft. 2 in. to 5 ft. 10 in.

PROCEDURES: The task required the movement of two target pieces, symmetrically and simultaneously, from the starting point of the near targets to the lighted far targets, placing them within .3 in. of the center of the target diameter. Feedback was provided by an audible tone. The rate of the task was kept constant at 3 seconds per cycle. Two hundred trials were administered at each angle with a 3 minute rest period between blocks of 50 trials. Between each block of 200 trials, a 10 minute rest period was provided.

APPARATUS: The table height was 25 in., measured from the floor to the geometric center of the work surface. The distance of the work station from the Ss was set so that the angle of abduction of the arm was 0° at the start position. The distance was measured as the horizontal component from the center of the biacromial distance to the geometric center of the work surface and it was kept constant. Work surface angles, as measured from the horizontal, were 0°, 6°, 12°, and 18°. Ss were seated on an improved type of standard industrial chair. The chair was placed along the longitudinal axis from the center of the work surface. The Variable Tracking Device required Ss to move two small cylinders .44 in. in diameter and .19 in. high, from two proximal light targets to two distal light targets, and return in a 3 second cycle. The near targets were separated by a distance of 2 in., while the far targets were 10.5 in. from their respective near targets on a line angled at 30° from the central longitudinal axis. The far targets were separated from each other by a horizontal distance of 13.5 in.

SIGNIFICANT RESULTS: Results indicated that the mean score when the work surface was at a 12° angle was significantly higher than when the work surface was positioned at the 0° angle, while the 12° angle work surface mean was higher ($p < .10$) than when the work surface was set an angle of 18° from the horizontal.

CONCLUSIONS/RECOMMENDATIONS: It was concluded that, with untrained college females, production efficiency at a work surface angle of 12° as measured by the ability to accomplish a simple manual task, both accurately and at a relatively high speed, was superior to the task performance when the work surface was positioned at the 0° or the 18° angle.

CATEGORY: ANTROPOMETRY

AUTHOR: Lewin, T.

TITLE: Anthropometric studies on swedish industrial workers when standing and sitting.

CITATION: Ergonomics, 1969, 12, 883-902.

RATIONALE: Knowledge of the working space required in standing and sitting postures is of fundamental importance for the design of correct ergonomic working postures. In Scandinavia there is a lack of anthropometric data on standing and sitting body postures for industrial employees. This paper reports the measurement of certain anthropometric dimensions of Swedish industrial workers.

METHODOLOGY:

SAMPLE SIZE: Eighty-seven males and seventy-seven females were used.

POPULATION CHARACTERISTICS: The ages of the subjects were 25 to 49. The subjects were selected using a random sequence from all employees in this age group at the Swedish Ball-Bearing Company (SFK) in Gothenburg.

PROCEDURES: An anthropometer was used for measurements on standing subjects. An apparatus consisting of an adjustable seat combined with two anthropometers, one for vertical and one for horizontal body movements was for measurements on the sitting subjects.

SIGNIFICANT RESULTS: Men have significantly higher means for the majority of heights above the floor or the seat. Height of seat increases more rapidly in women than in men with increasing distance between elbow and knee-joint. Women tend to have a larger increase in seat depth with increasing height of seat.

CONCLUSIONS/RECOMMENDATIONS: Since the standing heights of men are significantly higher than women, men and women appear to have essentially different requirements for the design of work place layout. Since women have relatively higher elbow height in standing than men, work tables should be higher for women than men of the same stature. Also, women require a larger depth of seat than men of same stature. This paper compared the present anthropometric dimensions to Akerblom's dimensions (dimensions top of knee and angle of knee to floor, as well as eye to seat and neck to seat). Akerblom's dimensions were significantly higher in terms of means than the SFK series, the exception was the eye to seat dimension in women. Differences were discussed in terms of different measuring techniques and differences in the composition of groups.

CATEGORY: SEAT DESIGN AND WORKPLACE DESIGN

AUTHOR: Lundervold, A.

TITLE: Electromyographic investigations during typewriting.

CITATION: Ergonomics, 1958, 1, 226-233.

RATIONALE: By recording electrical activity (EMG), it is possible to determine which muscles participate in movement, when they are contracted, and, to a limited extent, the force of contraction. This paper reviews some experiments which were carried out in order to investigate the most suitable position for working.

METHODOLOGY:

PROCEDURES: Subjects were allowed to adopt the position they themselves found most comfortable when sitting on a chair having a horizontal seat. The height of the seat above the floor was adjusted so that the typist sat with the entire sole of the foot planted on the floor with the knee bent at a right-angle.

APPARATUS: Electromyograms were recorded by means of a two-channel differential electromyograph and also with an eight-channel electroencephalograph. Both needle electrodes and surface electrodes were used.

SIGNIFICANT RESULTS: It was found that a number of the subjects could maintain their posture for a short time, without any action potentials being recorded in the trapezius, latissimus dorsi, and the sacrospinalis muscles. In all subjects, after a longer or shorter period, a continuous series of motor unit potentials were recorded. The action potentials in the muscles appeared, at first, in bursts, which gradually increased in duration, so that the corresponding "silent" periods between bursts diminished and finally disappeared. The length of time before the beginning of the continuous electrical activity in the dorsal muscles was decreased by the following procedures:

(1) Raising the seat of the chair, so that the feet of the writer did not reach the floor.
(2) Lowering the seat of the chair so that the right-angle formed by the knee became an acute angle.
(3) Changing the slope of the seat so that the writer was on the point of slipping.
(4) Crossing the knees.
(5) Sitting in an erect "military" position.
(6) Leaning forward.
(7) Performing a task in sitting position.
(8) When the person tested was tired.
(9) When the chair was unsteady owing to easy movable castors on the legs.

The continuous muscular activity could be stopped for a longer or shorter period in the following ways.

(1) When the writer changed his or her position on the horizontal seat.

(2) When the angle formed by the knee was altered, provided that the entire sole of the foot, in the new position, rested on the floor.

(3) By minor flections or extensions of the spinal column.

(4) By the use of the back-support, expecially in the lumbar region. The smallest number of action potentials were recorded when the person undergoing the experiment was sitting in a relaxed and well-balanced state of equilibrium, or was using a back rest.

CATEGORY: ANTHROPOMETRY, SEAT DESIGN, AND REACH ENVELOPE

AUTHORS: McFarland, R.A., Damon, A., & Stoudt, H.W., Jr.

TITLE: Anthropometry in the design of the driver's workspace.

CITATION: American Journal of Physical Anthropology, 1958, 16, 1-23.

RATIONALE: The present paper is concerned chiefly with the anthropometric aspects of physical anthropology. The paper consists of a summary of two larger publications (McFarland, Damon, Stoudt, Moseley, Dunlap and Hall, 1953; McFarland, Dunlap, Hall and Moseley, 1953).

METHODOLOGY:

SAMPLE SIZE: Three hundred-sixty commercial bus and truck drivers were used.

POPULATION CHARACTERISTICS: Two hundred subjects were from New England and New York; 60 subjects were from other states.

PROCEDURES: Thirty-two measurements pertinent to vehicle design were used.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: Anthropometrically determined dimensions of the cab area are determined from two different types of measurement of the human body: (1) static body measurements which consist chiefly of clearances (i.e., they are easily determined from a single body measurement and are applicable without modification to all workplaces) and (2) dynamic human body size based on functional body measurements (e.g., functional reach may differ significantly from anatomical arm length).

Cab dimensions related to static human body size include:

(1) Distance from seat to roof should be a minimum of 40.25 in. between the top of the seat cushion and the bottom of the cab roof (if seat is adjustable vertically, a minimum of 40.25 in. from the lowest position and a minimum of 36.25 in. from the highest position).
(2) Distance from the top of foot pedals to the lower edge of steering wheel should be a minimum of 15 in.
(3) Distance (horizontal) from lower edge of steering wheel to seat back should be a minimum of 15 in.
(4) Breadth of cab seat should be a minimum of 19 in.
(5) Seat depth should be approximately 17 in.
(6) Height of seat front above floor should be a minimum of 15 in.

(7) Range of vertical seat adjustment should at least be adjustable to 4 in. increments of 1 in. or less.

(8) Range of fore-and-aft seat adjustment should be 6 in. in increments of 1 in. or less.

Cab dimensions related to dynamic anthropometry include:

(1) Seat locations
   a) Vertical seat location - range of 4 in.
   b) Fore-and-aft seat location - range of 6 in.

(2) Placement of foot controls
   a) Clearance forward of pedals.
   b) Lateral distance between pedals.
   c) Lateral clearance for knees.

(3) Placement of hand controls
   a) No satisfactory way of predicting functional arm reach from anterior arm length.
   b) Body dimensions most pertinent include: height, weight, anterior arm reach, normal sitting, eye height, trunk height and shoulder breadth.

CATEGORY: SEAT DESIGN

AUTHORS: McFarland, R. A., Dunlap, J. W., Hall, W. A., & Moseley, A. L.

TITLE: Human Factors in the Design of Highway Transport Equipment.

CITATION: Boston, Massachusetts: Harvard School of Public Health, 1953

RATIONALE: The primary objective of this program was to improve safety and efficiency in operating all types of vehicular equipment. The purpose of this report was to summarize the design features of the cabs of representative trucks in current use. Each of twelve vehicles were considered both in terms of their suitability for the drivers who must operate them and possible accident inducing features inherent in the design.

METHODOLOGY

PROCEDURES: Information was gathered on each vehicle by following a detailed procedure.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: Seat height is always a critical factor in leg room, freedom, reflex time and fatique. The height of the seat front above the floor in the 12 vehicles ranged from 12.5 in to 18.5 in. The seat width ranged from 17.5 in. to 55 in. The seat depth ranged from 16 in. to 20.5 in. The height of the seat back ranged from 17.25 in to 21 in. The width of the seat back ranged from 17.5 in to 70 in. For seat adjustability, the paper recommends at least 4 in. for accommodating the middle 90% of the driver population with regard to an optimum eye level for visibility. The maximum height of the front of the occupied seat above the floor should be 15 in., thereafter downward adjustability becomes desirable. Other aspects of human sizing which are important in vehicle design, but most often neglected are (1) anterior arm reach, (2) knee height, (3) foot length and breadth, (4) hand length, (5) buttock-knee length, (6) abdomen depth, and (7) knee depth.

CATEGORY: SEAT DESIGN

AUTHORS: Mohr, G.C., Brinkley, J.W., Kazarian, L.E., & Millard, W.W.

TITLE: Variations of spinal alignment in egress systems and their effect.

CITATION: Aerospace Medicine, 1969, 40, 983-988.

RATIONALE: The study was conducted to investigate quantitatively the influence of seat geometry and personal equipment design factors on the intrinsic spinal curvature and vector relationship with the catapult thrust axis.

METHODOLOGY:

SAMPLE SIZE: Nine subjects were used.

POPULATION CHARACTERISTICS: The subjects were representative of the 5th, 50th, and 95th percentile sitting-height individuals.

APPARATUS: The roentgenometric investigation was accomplished using a Picker clinical x-ray unit. Two seats were used, the RF/F-4C seat which refers to the H-5 model, and the F-105. The angle between the seat pan and backrest of the F-4 seat measured approximately 115° whereas for the F-105 seat this angle was approximately 97°.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The study concluded that one of two lumbar pad cushions should be added to the seat. The lumbar pad cushion should either be 2.5 cm. thick or 7.5 cm. thick. Within the sample limits, a significant relationship of anthropometric dimensions to spinal position was not established. Spinal curvature was significantly altered by the F-4 seat backpad design.

CATEGORY: ANTHROPOMETRY

AUTHOR: Morant, G.M.

TITLE: Anthropometric problems in the Royal Air Force.

CITATION: British Medical Bulletin, 1947, 5, 25-31.

RATIONALE: The measurements taken in this study were designed to assess the space occupied by the body in different positions, rather than the proportion of its anatomical parts.

METHODOLOGY:

APPARATUS: Stature, sitting height, length of arms and legs were taken with the aid of a measuring board. The two wings of the board were fixed so that they were perpendicular to one another. Horizontal and vertical scales with 0.5 in. (1.25 cm.) intervals were marked on them. In finding body-girths, a constant pressure tape was used.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: By themselves, the body measurements cannot give any precise answer to the question of what the major dimensions of a cockpit should be and of where the controls can best be placed. These questions can only be investigated satisfactorily by carrying out experimental investigations.

CATEGORY: SEAT DESIGN

AUTHORS: Morgan, C.T., Cook, J.S., Chapanis, A., & Lund, M.W.

TITLE: Human Engineering Guide to Equipment Design.

CITATION: New York: McGraw-Hill Book Company, Inc., 1963.

RATIONALE: Seats should vary in design according to their intended purpose and the physical characteristics of their users. All seats should accommodate as many of the user population as possible. It should be remembered that good seating design is generally low in cost compared to the total equipment cost per operator, but it can be a very important factor in operator efficiency.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Seat pan shape: Most seat pans should be flat rather than shaped. If the occupant is virtually immobile for many hours, seats with cut-outs or depressions under the boney protuberances are more comfortable and efficient than flat seat pans.

(2) Seat pan upholstery: The seat pan should be cushioned with 1 to 2 in. of compression.

(3) Seat height: For the general purpose seat, the height should be 15-16 in. If forced to choose between too low and too high a seat, the lower should be chosen.

(4) Seat length: The best general-purpose seat length is about 17 in.

(5) Seat width: A reasonable dimension for seat width is 18 in. Any width below 17 in. is too small.

(6) Seat pan angle: The best seat pan angle is around 6°-7°, although the range usually varies from the horizontal to 12°.

(7) Backrest height: For back support, the backrest should extend at least 18-20 in. above the seat pan. For head support, the backrest should be 34 in. high. A small-of-the-back support is provided by a backrest 5-6 in. high that has its bottom edge 6-7 in. above the seat pan.

(8) Backrest width: For the small-of-the-back support, a width of 12-13 in. will suffice. Where the seated operator can rest or relax, at least a 20-in. wide backrest will provide full support across the shoulders.

(9) Backrest angle: A backrest inclined 103° to 115° will be comfortable.

(10) Backrest curvature: A small-of-the-back support should have a lateral curvature equivalent to the arc of a circle 7.3 in. in radius.

(11) Armrests: When armrests do not interfere with necessary body movements, they should be provided to increase the operator's comfort. The armrest height should be 8-10 in. above the seat pan, but whenever possible, the operator's arm should be supported so that it lies in the same plane as the work surface.

(12) Footrests: The footrest should allow each foot to be about normal (90°-100°) to the lower leg. If the footrest is at an angle of more than 20° from the horizontal, a heel support should be provided.

(13) Workplace clearance: For fore-and-aft clearance between the backrest and the front of the knees, 26.5 in. will accomodate almost everyone. A vertical distance of 12 in. is desirable between seat and work surface, with a minimum of 24.5 in. between the floor and the underside of the work surface.

CATEGORY: ANTHROPOMETRY

AUTHOR: Moroney, W.F.

TITLE: Selected bivariate anthropometric distributions describing a sample of naval aviators-1964.

CITATION: NAMRL-1130, Pensacola, Florida; Naval Aerospace Medical Research Laboratory, 1971.

RATIONALE: Previous anthropometric surveys were limited to a consideration of each anthropometric feature independently. Designers also need knowledge of the interaction between variables. This report extends data previously collected from 1549 naval aviation personnel by presenting bivariate tables that illustrate the relationship between selected variables.

METHODOLOGY:

SAMPLE SIZE: Measurements of 1549 naval aviation personnel (Gifford, Provost, Lazo, 1964).

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The paper concludes that since the individual who is large (or small) on one dimension is not necessarily large (or small) on all other dimensions, bivariate tables (as a minimum) must be used when workspaces are being designed.

CATEGORY: ANTHROPOMETRY

AUTHORS: Moroney, W.F., Kennedy, R.S., Gifford, E.C. & Provost, J.R.

TITLE: Selected Anthropometric Dimensions of Naval Aviation Personnel.

CITATION: Pensacola, Florida: Naval Aerospace Medical Research Laboratory, August 10, 1971, NAMRL-1141.

RATIONALE: Physical and academic requirements for entrance into the flight program have changed since the previous study (Gifford, Provost, & Lazo, 1964) of anthropometric features of naval aircrewman was conducted. The present study was undertaken to determine if these changes, combined with changes in the anthropometric features of the population in general, have been reflected in the bodily dimensions of the naval aircrewmen trainees and compares these measures with data obtained from the Naval Air Development Center (NADC) and the USAF Aeromedical Laboratory (AML).

METHODOLOGY:

SAMPLE SIZE: 6534 aviation training candiates were used.

POPULATION CHARACTERISTICS: The subjects were college graduates. All subjects had to meet the following measurements as stated in BUMED Instruction 6110.8: physical standards: minimum stature- 64-78 in.; sitting eye height - 32-41 in.; buttock-leg length - 36 50 in. All Ss were student naval aviators or student naval flight officers entering training between Jan. 1969 and Aug. 1969. The mean age of the subjects was 22.7 years.

APPARATUS: The apparatus included the Provost and Gifford (1964) design of an integrated anthropometric measuring device as specified in BUMED Instruction 6110.8. The device measured weight, stature (standing height), sitting height, shoulder width, trunk height, buttock-knee length, buttock-heel length, and functional reach.

SIGNIFICANT RESULTS: Inconsistencies were noted in the measurement of trunk height and functional reach. These were traced to unauthorized modifications of the measuring device - therefore, no data on these measurements was included in the report.

Results show that subjects in the present sample differed from the NADC sample in mean values as follows: (a) 4.25 lb. lighter, (b) .21 in. taller, (c) sitting height - .48 in. taller, (d) shoulder width - .90 in. narrower, (e) buttock-knee length - .45 in. longer, and (f) younger than the NADC sample. The present sample differed from the AML sample as follows: (a) 3.49 lbs. heavier, (b) 1.04 in. taller, (c) .82 in. taller in sitting height, (d) .92 in. longer in buttock-knee lengths, (e) 1.16 in. longer buttock-heel lengths, and

(f) also younger. Significant differences ($p < .01$) were found between the means for each variable except for shoulder width which was identical for the present (NAMI) and AML samples. Correlations were reported. As expected, stature correlated well with segmental and limb lengths, while weight correlated well with breadth and mass-related factors.

CONCLUSIONS/RECOMMENDATIONS: The difference in weight between NAMI and NADC groups may be, in part, attributed to the selection process. The majority of the NADC subjects were not college graduates, as opposed to the NAMI sample. It is thus reasonable to expect a wider range in weight in the NADC sample and a higher mean weight, since Stoudt, et. al. cites a study by the American College Health Association which shows that college students had an average weight of 3 lbs. less than noncollege students of the same age.

A simiilar rationale could explain the differences in stature, sitting height, and buttock-knee length between the NAMI and AML groups. In addition to a general trend for the population as a whole to become taller, Stoudt et. al. reported that college students (of the same age as the NAMI sample) are taller than noncollege students of the same age group. Other differences are accounted for in terms of the trend for the population to become larger and in terms of the differences in the ages of the different samples.

CATEGORY: ANTHROPOMETRY

AUTHOR: Moroney, W.F. & Smith, M.J.

TITLE: Empirical reduction in potential user population as the result of imposed multivariate anthropometric limits.

CITATION: NAMRL-1164. Pensacola, Florida: Naval Aerospace Medical Research Laboratory, 1972.

RATIONALE: Workspaces, from desk top consoles to aircraft cockpits, have traditionally been designed to accommodate the "average man" (50th percentile on all anthropometric features) or individuals included within some specified range about the median (5th through 95th percentiles; 1st through 99th percentiles, etc.). This paper examines the impact of using pre-established critical limits (anthropometric percentiles) as the basis of excluding individuals from the user population.

METHODOLOGY:

SAMPLE SIZE: 1549 naval aviation personnel measured on 96 anthropometric features from Gifford, Provost, and Lazo (1964) were used.

PROCEDURES: Thirteen anthropometric features were selected that were appropriate for use in automobile or console design.

SIGNIFICANT RESULTS: Only 43.38% of the sample used in this investigation had anthropometric features which fell within the critical limits for the 5th-95th percentiles on all of the 13 variables. Considerably more are included when the critical limits for the 3rd-98th percentiles are used - 67.74%. Thus, 52.62% and 32.26% of the potential user population would be excluded if the critical limits for the 5th-95th and 3rd-98th percentiles, respectively, were stringently applied in workspace and equipment design.

CONCLUSIONS/RECOMMENDATIONS: To design workspace without an awareness of the interaction between anthropometric variables ultimately leads to a considerable reduction in the size of the accommodated population. Consequently, it is important to consider the relationship between anthropometric features in determining anthropometric compatibility. The authors propose a preparation of bivariate data, which is not variable specific but which could be used when the correlation between anthropometric features is known.

CATEGORY: ANTHROPOMETRY

AUTHORS: Moroney, W.F. & Smith, M.J.

TITLE: Intercorrelations and Selected Descriptive Statistics for 96 Anthropometric Measures on 1549 Naval Aviation Personnel.

CITATION: NAMRL-1165, Pensacola, Florida; Naval Aerospace Medical Research Laboratory, 1972.

RATIONALE: A previous report by Moroney and Smith (1972) showed the need for designers to consider the correlations between anthropometric features when designing workspaces. This paper reports the correlations between 96 anthropometric features.

METHODOLOGY:

SAMPLE SIZE: 1594 naval aviation personnel (Gifford, Provost & Lazo, 1965) were used in the correlations between anthropometric features.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: An earlier report by Moroney and Smith (1972) demonstrated an extreme reduction in potential user population as a result of the use of pre-established anthropometric percentile design limits. The elimination of such a considerable proportion of the potential user population results from the fact that variables used in establishing design limits are often only moderately oorrelated with one another, and persons with extreme values on one variable are likely to be near average on another. The present paper provides the correlations between different anthropometric features.

CATEGORY: ANTHROPOMETRY, SEAT DESIGN, AND WORKPLACE DESIGN

AUTHOR: Morrison, J.F.

TITLE: Design of machinery and protective equipment to take account of static and dynamic anthropometrical measurements.

CITATION: The South African Mechanical Engineer, 1965, 230-233.

RATIONALE: Anthropometrical data are important in designing the seats for drivers and operators, as well as in the design and positioning of the controls and the arrangement of the instruction display. Dimensions given in this paper were from a sample of 200 laborers of a Bantu mine population and a population of American flying personnel.

METHODOLOGY:

SAMPLE SIZE: Two hundred laborers of a Bantu mine population were used as Ss.

POPULATION CHARACTERISTICS: The dimensions of the American male population were from Hertzberg & Daniels (1950).

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(American population dimensions in parenthesis)

(1) Seating: The seat should be approximately 2 cm. lower than the popliteal height of those with shorter legs. The mean popliteal height for the mine population was 43 cm. (43) and the fifth and 95th percentile measurements were 36 cm. (40) and 45 (46) respectively (shoes and boots increase this height 2.5 and 4 cm. respectively). Suitable seat depth is 40 cm. The seat should slope backwards 5 to 7 degrees. Support for the lumbar region should be 13 cm. high and 20 cm. above the seat pad. The armrest from seat to elbow should be 25 (27) cm. in heighth.

(2) Position of controls: The angle formed by the shoulder-hip and hip-knee segments should not be less than 85° and not more than 105°. If maximal pressure is to be supplied, the leg should almost be in a straightened position. For slight pressure, the upper limit of a 120° angle is generally accepted. The height of the seat determines the position of the foot controls. With a high seat the controls should be placed nearer than in the case of a low seat. The mean distance from the back of the seat to the heal when the leg is extended was 102 (109) cm ; the 5th and 95th percentile was 91 (97) cm.

(4) Working surface: At least 18 cm. should be provided between the top of the seat and the edging underneath the table. A minimum space of 90 cm. from the back of the seat to the front of the toes is recommended. Workers were more efficient when working on a work surface height which was 5 to 15 cm. below the elbow height. The optimum speed in hand movements was attained on a working surface level 7 cm. below the elbow (McCormick, 1957). The mean elbow height of the Bantu population was 107 (111) cm. The eye height, which was 157 (164) cm. in the standing position and 75 (80) cm. in the sitting position, is generally regarded as the maximum height of displays. The optimum space for controls lies between the shoulder and knuckle heights, which were 139 (144) and 72 (76) cm. respectively above the floor.

CATEGORY: SEAT DESIGN

AUTHORS: Murrell, K. H.

TITLE: Ergonomics.

CITATION: London: Chapman and Hall, 1969.

RATIONALE: Most people at work are sitting on seats which are badly designed and generally too high. This review was based on two important considerations: (1) a good seat should enable the user to change posture at intervals so that different muscle groups may be called into play; at the same time the use of a well designed and positioned back-rest may relieve the back muscles of a good deal of postural work; (2) a good seat should not press unduly on the tissue of the thigh which is not designed to withstand pressure as is the tissue of the buttocks.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Seat height must clearly be related to the length of the lower leg from the underside of knee to the heel (popliteal height) and to the curvature of the thigh. An adjustable seat for females should range from 14 to 17.5 inches, for males the range should be from 15 to 18.5 inches. A fixed height for females should be between 15 to 15.5 inches, for males approximately 16.5 inches. A seat of fixed height to accommodate both males and females should have a height between 16 to 16.5 inches.

(2) Foot rests may be used to accommodate the smaller members to seat height. The foot rest should be a flat surface rather than a bar, which will cause fatigue by forcing the operator to keep his feet in a fixed position.

(3) Seat depth should be sufficient to allow the buttocks to move to permit changes of posture but should not be so great that the seat cuts into the back of the knee. The seat depth should be approximately 15 to 16 inches.

(4) The front edge of the seat should be curved to avoid having a sharp edge to cut into the underside of the thigh.

(5) Seat width should be sufficient to allow a certain amount of movement of the buttocks. Seat width should be 17 inches. If the seat has arm rests, the seat should be 19 inches wide.

(6) The arm rests should be 8.5 to 9 inches above the seat and should project 10 to 12 inches forward from the back of the seat.

(7) The seat pan should slope backwards 3° to 5°.

(8) Shaped seats are undesirable.

(9) The back rest should be curved to a radius of about 16 inches and should be sufficiently high to allow the buttocks to protrude beyond the back rest when a person is sitting erect. The opening should not be less than 8 inches above the seat. The depth of the back rest should be about 4 to 8 inches and it should not be more than about 13 inches wide.

(10) There should be no obstructions under the front part of the seat.

CATEGORY: SEAT DESIGN

AUTHOR: Nissley, H.R.

TITLE: A study of factory chairs.

CITATION: Management Review, 1949, 38, 669-671.

RATIONALE: The paper reports a 2-year study of factory chairs involving leading chair manufacturers and other plants. The study involved interviewing plant managers, foremen and operators by a questionnaire survey technique.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) A main consideration in the selection and use of a factory chair is "how comfortable is it?" A comfortable chair included the deep form-fitting seat which was greatly preferred to the flat or slightly curved seat. A seat curvature that approached the curvature of the buttocks was better than no seat curvature at all.

(2) Another consideration is "how safe is it?" Rounded, blunt edges and corners were better than sharp pointed edges. Bucket or saddle seats were safer than flat, polished rounded seats.

(3) A third consideration is "it it easily adjustable?" Adjustments were usually too restricted in most instances. For example, the chair adjustment limit was usually 4 in. which restricted the use of the chair to a few jobs of the same type.

(4) The last consideration is "low maintenance costs." Any chair rating high in these characteristics (a) will increase production (by reducing fatigue and frequent absence from work center); (b) will reduce accidents from falls, scratches, and bruises; and (c) will save time and patience of operators and foremen in making chair adjustments particularly in multi-shift operations.

CATEGORY: SEAT DESIGN

AUTHOR: Nissley, H.R.

TITLE: Is there an ideal factory chair?

CITATION: Mill and Factory, 1951, 49, 125-126.

RATIONALE: The paper reports a four-year study of factory chairs. The study included 150 operators and 18 foremen and work managers.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The study recommended the following points important to factory chairs:

(1) The chair should be quickly adjustable (without tools) in height.
(2) The backrest should have a horizontal (vertical) adjustment. The backrest should have a lateral adjustment.
(3) The seat should be form-fitting.
(4) Footrests should be provided and they should be easily adjustable in height.
(5) The factory chair should be a combination swivel and non-swivel chair. The ideal factory chair would be one which could be converted at the operator's will from a swivel to a non-swivel without any sacrifice in safety.
(6) The backrest should have a small radius. The radii of conventional backrests ranged from 12 to 14 in. A backrest having a radius of 9 in. was found to be ideal for both heavy and light people.

CATEGORY: SEAT DESIGN

AUTHOR: Nissley, H.R.

TITLE: Is there an ideal factory chair?

CITATION: Management Review, 1952, 41, 175-176.

RATIONALE: There are several considerations in the selection and use of a factory chair. These include the following:

(1) How comfortable is it?
(2) How safe is it?
(3) Is it easily adjustable?
(4) What are the annual maintenance costs of the chair?

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: An ideal factory chair for lower maintenance and higher productivity should include:

(1) An adjustable backrest-both vertically and laterally.
(2) Perforated deep bucket type seat plate.
(3) Vertical seat adjustment.
(4) A swivel, non-swivel screw.
(5) A vertical footrest adjustment.
(6) Hardened steel glides.
(7) Long chair feet to prevent easy tipping.
(8) Back rest of an 8-9 in. radius.

CATEGORY: ANTHROPOMETRY

AUTHORS: Oshima, M., Fujimoto, T., Oguro, T., Tobimatsu, N., Mori, T., Tanaka, I. & Watanabe, T.

TITLE: Anthropometry of Japanese Pilot.

CITATION: AMRL-TR-65-74, Wright-Patterson Air Force Base, Ohio, Aerospace Medical Research Laboratory, 1965.

RATIONALE: The results of an anthropometric survey of 239 pilots of the Japanese Air Self-Defense Force are presented. Comparisons with the 1950 USAF flying population are made.

METHODOLOGY

SAMPLE SIZE: Subjects were 239 Japanese pilots.

PROCEDURES: 62 body dimensions were measured.

SIGNIFICANT RESULTS:

Measurement	Mean	S.D.
Weight	61.12 kg.	5.86
Height	166.89 cm.	4.80
Cervicale height	141.16 cm.	5.08
Sitting height	90.78 cm.	2.62
Knee height	49.06 cm.	2.37
Popliteal height	39.79 cm.	2.06
Shoulder-elbow length	34.44 cm.	1.63
Forearm-hand length	44.38 cm.	1.73

CATEGORY: SEAT DESIGN

AUTHOR: Oxford, W. F.

TITLE: Anthropometric data for educational chairs.

CITATION: Ergonomics, 1969, 12, 140-161.

RATIONALE: In 1965, an anthropometric survey was conducted to obtain 11 measurements of 12,000 pupils of all grades, including 400 teachers. Girls have reached 65% of their total stature at the age of 4, and 95% at the age of 13. After that, the average girl can expect to grow an additional 8 cm. in height. Boys attain 60% of their total stature at the age of 4, and 95% at the age of 15 and can expect to grow a further 8 cm. in height.

METHODOLOGY: N/A

SIGNIFICANT RESULTS:

		Seat to eye (cm.)		Seat to scapula (cm.)		Seat to elbow (cm.)		Popliteal to Buttock (cm.)		Heel to popliteal (cm.)	
Years	Sex	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
13-14	female	71.2	3.6	41.2	2.7	22.6	2.6	44.9	2.6	39.4	1.8
	male	68.7	4.6	38.4	3.2	21.6	3.0	43.7	3.0	40.6	2.4
14-15	female	72.8	3.4	41.5	2.8	22.8	2.4	46.4	2.7	39.5	2.1
	male	73.0	4.6	41.4	3.2	22.9	3.0	46.7	3.0	41.9	2.4
15-16	female	73.1	3.2	45.2	2.5	22.6	2.4	47.0	2.7	39.6	2.2
	male	76.9	4.3	43.8	3.0	23.7	2.9	47.9	3.2	43.7	2.4
16-17	female	74.0	3.2	43.1	2.7	23.5	2.7	46.9	2.7	39.5	1.9
	male	79.3	3.9	45.4	3.5	25.0	2.8	48.7	3.0	44.2	1.9
17-18	female	75.1	3.9	44.0	2.6	24.2	2.7	47.3	2.7	40.6	1.9
	male	80.3	3.9	46.6	3.1	25.8	2.9	49.6	2.7	44.2	3.0
18-19	female	74.7	3.0	43.8	2.7	23.6	2.7	46.8	3.3	41.0	2.2
	male	80.1	3.6	46.1	2.9	25.3	3.4	50.3	3.5	44.3	2.2
19-20	female	75.5	3.2	44.5	2.6	23.8	2.7	46.3	3.2	40.1	2.2
	male	80.8	3.5	46.3	2.7	24.9	3.4	50.5	3.5	44.4	2.3
Over 20	female	75.6	3.5	43.2	3.0	23.8	2.6	46.1	3.1	40.2	1.9
	male	79.5	3.7	45.8	2.9	26.2	2.7	49.1	3.2	43.2	2.1

CONCLUSIONS/RECOMMENDATIONS:

(1) The seat should be curved slightly at the front. Dished seats and saddle seats restrict movement.

(2) Tables with sloping tops improve posture.

(3) Structural details are given for wood and metal tables and chairs manufactured and supplied to schools by the Department of Education, Australia (based on 1965 Anthropometric Survey).

Height of seat - 17.5 in.
Width of seat - 14 in.
Depth of seat - 14.5 in.
Space between seat & back support - 8 in.
Depth of back support - 15.5 in.

The dimensions are for the largest chairs to be used by the Department of Education, Australia.

CATEGORY: ANTHROPOMETRY AND SEAT DESIGN

AUTHORS: Rice, E.V. & Ninow, E.H.

TITLE: Man-machine interface: A study of injuries incurred during ejection from U.S. Navy aircraft.

CITATION: Aerospace Medicine, 1973, 44, 87-89.

RATIONALE: The paper determined the correlation between body measurements of injured and non-injured ejectees by seat and aircraft model.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) The median sitting height was found to be 36.7 in. The majority of individuals with sitting heights below and above, as well as in the median range, ejected without receiving a back injury.

(2) It was found that 25% of those using the lower ejection handle sustained injury as against 15% of the face curtain users, fifty-six percent of the lower handle user's injuries were incurred by individuals who were below the median in sitting height. Functional reach was checked to determine whether a short reach could force a pilot to lean forward, and it was found that slightly more than half of the measurements were below 30 in. which is approximately the 15th percentile. Apparently a below-averaged-sized person runs less risk of injury if he uses the face curtain.

(3) Median buttock-knee length measurement was established as 24.2 inches. No leg injuries were sustained by over 90% of those in the low measurement ranges (22 in. and below). They comprised 14% of the population and received 7% of the total injuries. The 23 in., 24 in., and 25 in. group together represented 76% of the population and received 75% of the leg injuries. Injuries increased in the 26 in. group, but in the 27 in. group (consisting of 10 persons) there was only one minor injury.

(4) It was concluded that extremes of anthropometric measurements are responsible in only a few instances of significant injury, and that poor body position and unfavorable ejection conditions, rather than body measurements, are responsible for egress injuries in the majority of ejections.

CATEGORY: SEAT DESIGN

AUTHOR: Ridder, C. A.

TITLE: Basic design measurements for sitting.

CITATION: Agricultural Experiment Station, University of Arkansas, Fayetteville, Oct., 1959, Bulletin 616, 91 p.

RATIONALE: This study sought basic design measurements (including variations in size) needed to support adults in common types of sitting postures. It's threefold purpose was to uncover: (1) The basic design measurements for sitting, (2) The basic types of sitting positions, and (3) The basic sizes for each of the types of sitting position.

METHODOLOGY:

SAMPLE SIZE: One hundred twenty-nine adults (58 men and 71 women) were used as subjects.

POPULATION CHARACTERISTICS: Height and weight of adults in the total population was used as the basis for subject selection. An effort was made to include a wide age distribution.

PROCEDURES: The position for each part of the chair was recorded for each subject for each of the five types of chair activity: (1) Dining (2) Writing (3) Playing table games (4) Talking and (5) Relaxing.

APPARATUS: The experimental chair was designed to allow for the greatest possible variation in heights, depths, slants, and shapes of seats, backs, and armrests. The chair consisted of three parts: seat, back, and armrests. The seat was made of a series of aluminum plungers or pins inserted into carefully calibrated holes drilled into a wooden base. Pins were capped with circular rubber tips somewat concave in shape. A steel spring of five pounds strength was inserted between the wooden base and the cap so that the plungers adjusted to the shape of the individual sitting on them. Each pin was designed to lock at whatever depth it was depressed. For the back, aluminum plungers capped with rubber discs were boxed between two layers of wood in a manner similar to the seat design. No springs were used on these pins; they were adjusted by a person standing behind the chair. The chair back was adjustable as a whole slant was adjustable and the entire back could be moved forward or backward. The armrests were adjustable in height and in distance apart; they could also be turned horizontally and vertically to suit the person sitting in the chair.

SIGNIFICANT RESULTS: (Note: Due to [illegible] large amount of data reported by Ridder, only the results for [illegible] for dining, writing, and playing table games are reported here.)
Ridder found the following dimensions and adjustments to be optimal:
(1) Seat Height should be [illegible] inches at the front lowest point; 17 inches at the front highest point (side); 14.2 inches at the back

lowest point; and 16.5 inches at the back highest point.

(2) Slant of Seat should be one-half inch from the front to the back.

(3) Depression of Seat should be provided either by molding or by pressure of the person seated. Depression should be as follows: 1 inch from side to lowest point at the front and 2-1/2 inches from side to the point of greatest depression toward the back of the seat.

(4) Seat Depth should be 16.5 inches from the front to the back; 11.5 inches from the front to the point of lowest depression.

(5) Seat Width: The minimum seat width (if the sides are partially enclosed) should be 17 inches at the front of the seat and toward the back of the seat before the narrowing curve, which starts about three inches from the front of the seat.

(6) Back of Chair: Height should be 17.5 inches in a diagonal line from the seat to the top of the chair back. Width should be 13.5 inches across the top and 10.0 inches across the bottom. Slant should be 15° back from true vertical. Depth of chair back should be as follows: At 1.5 inch intervals up the center of the chair back starting 4.5 inches above the chair seat measurements should be:
16.3 inches at 4.5 inches above the chairseat;
16.6 inches at 6 inches above the chairseat;
17 inches at 7.5 inches above the chairseat;
17.3 inches at 9 inches above the chairseat;
17.8 inches at 10.5 inches above the chairseat;
18.3 inches at 12 inches above the chairseat; and
18.7 inches at 13.5 inches above the chairseat.
The depth of the chair back must be considered in relation to the depth of the chair seat.

(7) Armrest of the Chair: The single best width between armrests is 20 inches between the inner edges. The best height is 8 inches from the side of the chair seat. If the chair is to be used with a table having an apron or desk having a shallow center drawer, 7.5 inches should be left free back from the front of the seat to the front of the armrests.

CONCLUSIONS/RECOMMENDATIONS:

(1) The three main types of sitting positions preferred by adults were (a) the erect position, preferred near a table, a desk, or other surface while dining, writing, or playing table games; (b) the less erect more relaxed position preferred mainly for conversation, listening, or viewing, and (c) the relaxed position preferred while reading, watching TV or informal conversations.

(2) Seating preferences for three activities associated with tables or desks (i.e. dining, writing, playing table games) were determined separately. It was found that the body positions preferred and hence the basic design measurements for all three were very similar.

(3) The following conclusions on the heights of seats were made:
(a) In applying these heights, it should be remembered that older people and infirm people find it difficult to arise from chairs that are low unless firm arm supports are supplied.
(b) When seated, the body loses leverage as the seat height is lowered. It is more difficult to reach or to handle materials,

such as large charts, when sitting on a low seat than when sitting on a high stool even though the relation of the table height to the seated body is the same.

(4) The following conclusions concerning the depth of seats were made:

(a) Shorter seat depths make the back of a chair or sofa a real support for the seated individual.

(b) Considering the depth of the seat, it should be remembered that body leverage is lost as seat depth is increased; freedom of leg movement is lost as seat depth is increased; and limb movement becomes difficult as the body weight increases.

(c) Individuals with heavy limbs tend to prefer somewhat deeper seats. Apparently since they cannot move their limbs easily, they prefer to have more of their greater weight supported.

(5) It was concluded that greater comfort is obtained in a seat in which it is possible to shift the weight of the body from time to time. The basic design measurements allow an individual to shift his weight back and forth in the seat.

(6) Since the proportions of the basic design measurements (stated in the Results section) are based on the proportions of the human body, they should result in designs that are most pleasing both functionally and aesthetically.

CATEGORY: ANTHROPOMETRY

AUTHOR: Roebuck, Jr., J.A.

TITLE: Anthropometry in aircraft engineering design.

CITATION: Journal of Aviation Medicine, 1957, 28(1), 41-56.

RATIONALE: The paper provides a description of a program developed by an airframe manufacturer (Douglas Aircraft) to compile and apply anthropometric data. The purpose of the program was to demonstrate requirements for an integrated, practical approach to the problem of economically providing space for human operators and passengers within the limitations of aircraft design.

METHODOLOGY:

PROCEDURES: The following are steps for the collection and use of anthropometric data in aircraft design;

(1) Procurement of basic data.
(2) Reduction to standards.
(3) Engineering presentation.
(4) Design and development - Aid and interpretation.
(5) Production and sales - consultation.
(6) Evaluation and recording.

SIGNIFICANT RESULTS: Emphasis was placed on the importance of the means of communication of anthropometric data to engineers, in terms of design applications. The paper also discussed standardization of data accumulated from diverse sources and the development of some detailed statistical techniques for estimating unmeasured dimensions.

CONCLUSIONS/RECOMMENDATIONS:

(1) Recommends the use of the 6 steps for the collection and the use of anthropometric data (see method section).
(2) Recommends the use of normal probability graphs and tabular presentation for comparison and easy use of anthropometric data.
(3) Recommends several methods for correctly estimating unknown anthropometric dimensions from other dimensions.
(4) Recommends several methods for use of anthropometric data in design problems.
(5) Recommends the use of mannikins (5th, 50th, & 95th percentile) in designing.
(6) Recommends the use of mockups in design problems.

CATEGORY: SEAT DESIGN

AUTHORS: Rosener, A.A. & Stephenson, M.L.

TITLE: Final Report for Shuttle Passenger Couch.

CITATION: Martin Marietta Corp., Jan. 1974, MCR-74-40, DRL No. T-774.

RATIONALE: This paper describes the design, fabrication, and testing of a shuttle passenger couch which would provide the occupant a safe support during launch and entry modes and yet provide a comfortable personal area designed for relaxation, sleeping, eating, and clerical work in zero-gravity.

METHODOLOGY:

PROCEDURES: Industry and commercial airlines were consulted concerning couch requirements.

SIGNIFICANT RESULTS: Preliminary tests showed an increase in stature of Ss from standing to supine measurements. A 95th percentile subject's stature increased to the point where interference occurred in the passenger couch engineering model flatbed position. This increase in stature can be expected in a zero-g environment. From projected 1980 anthropometric dimensions of man, the minimum internal length of 75.5 in. and the minimal internal width of 21 in. are required to accept the 95th percentile male when lying on his back. An additional 5 inches in length and 3 inches in width must be added to provide structural integrity and vehicle interface provisions.

CONCLUSIONS/RECOMMENDATIONS:

(1) The seat can accommodate the 5th through 95th percentile males.
(2) It was recommended that the requirement for adjustable seat depth be eliminated and only the 5th percentile male dimension (17.5 in.) be used. This would provide a savings in cost and weight and would be usable by the entire male percentile range.

CATEGORY: SEAT DESIGN

AUTHORS: Shackel, B., Chidsey, K.D., & Shipley, P.

TITLE: The assessment of chair comfort.

CITATION: Erogonomics, 1969, 12, 269-306.

RATIONALE: This paper describes a series of studies to explore the general area of seating comfort. The aim of the paper was to explore methods and to compare a group of chairs in typical usage tasks. A second purpose of the paper was to study the value of individual opinions and British Standard dimension recommendations as methods for users to select chairs.

METHODOLOGY:

SAMPLE SIZE: Twenty Ss were selected on the basis of their stature, with the aim of covering the 5% to 95% range of the normal population. The range of the males was 63.5 to 72.5 in. and the females was 59 to 68 in. The Ss were also selected to be within ±1 S.D. of the mean weight for their height.

For experiment 2 eight ergonomists from Britain (one female and seven males) were used. The height range of the males was 159 to 183 cm., and the height of the female was 63 in. Their weights were within approximately ±1 S.D. of the mean of their body weights.

PROCEDURES: Experiment 1 consisted of 3 separate experiments, with the same chairs and three panels of 20 Ss, under the conditions of (1) long-term sitting, (2) sitting at a desk, and (3) eating a meal.

Experiment 2 consisted of subjects sitting in the chairs for two minutes and then filling out a comfort rating scale for (1) his personal comfort and (2) how he would predict he would feel at the end of one hour. Secondly, the subject was asked to rank them on the comfort he assessed they afforded for the general population (5th to 95 percent range). Next the subject was given a copy of the British Standards Institute recommendations and the full dimensions of the chairs. Without seeing the chairs, subjects were asked to rank them (1) for comfort for long-term sitting and (2) for comfort for office use. Finally the subject was allowed to see and sit on the chairs and asked to rank them again for the general population (1) for comfort for long-term sitting and (2) for comfort for office use. In the previous rankings subjects were not allowed to see the chair.

SIGNIFICANT RESULTS: The results of Experiment 1 were as follows:

(1) There were hardly any significant differences between the ratings of male and female subjects.
(2) There was a significant decrease in comfort ratings with time.

(3) There were significant differences in comfort ratings between chairs.
(4) There was a significant correlation between rankings before trials and comfort test results, suggesting a possible useful technique.

The results of Experiment 2 were as follows:
(1) Experts in ergonomics research on sitting comfort do not appear able, either on an opinion basis or from chair dimensions and British Standard recommendations, to give accurate comfort assessments, e.g., to select either best or worst chairs for use by a general population.
(2) Experts differ markedly in their ability to rank chairs for affording comfort to the general population, and they cannot give accurate rankings for use as a substitute for actual sitting trials.

CONCLUSIONS/RECOMMENDATIONS: Further analyses of some results yield, in particular, significant correlations and differences between comfort test results and chairs ranked by size from B.S.I. recommended dimensions, suggesting the need for further work to improve recommendations and a useful technique for such studies. The general conclusion seems to be that seating comfort is a very complex problem and the only valid approach is the experimental method.

CATEGORY: CONSOLE DESIGN

AUTHORS: Siegel, A.I. & Brown, F.R.

TITLE: An experimental study of control console design.

CITATION: Ergonomics, 1958, 1 (3), 251-257.

RATIONALE: The study systematically evaluated the angular orientation of the side panels of an operator's console for both single and/or paired operator's condition. The aim of the design was to minimize body, arm, and chair movements necessary to manipulate controls, as well as to optimize vision with minimum head movement.

METHODOLOGY:

SAMPLE SIZE: Subjects included 11 single operators and 6 pairs of operators.

POPULATION CHARACTERISTICS: The height of the men ranged from 5 ft. 6 in. to 6 ft.

PROCEDURES: Ss followed sequence of verbal instructions to use the controls on the panels. Criteria included (1) objective criteria of average number of seat movements, average seat displacement, average body movements (number and extent), average number of arm extensions (part and full), (2) subjective criteria based on the subject's responses of degree of ease or difficulty, judgments that the panels should be wider apart or closer together, and preference ranking for the four angles. Each series consisted of 12 programs - 3 programs for each of the four side panel angles.

APPARATUS: A 48 in. front panel with side panels at 35°, 45°, 55°, and 65° was employed. The seat height for the console was 18 inches. The seat was a desk-type upholstered swivel chair with arms.

SIGNIFICANT RESULTS: Single operators could work at any angle up to 65°. On the other hand, paired operators found 45°-55° the optimal inward angle for side panels, both subjectively and empirically. From the paired operator visual block data, it appears that difficulties arise with angles greater than 55°.

CONCLUSIONS/RECOMMENDATIONS: The paper recommends the selection of an angle of 50°-55° to be the best resolution of the conflicting effects of side panel angle, when paired operator and single operator situations are assigned equal importance.

CATEGORY: CONSOLE DESIGN

AUTHOR: Shackel, B.

TITLE: A note on panel layout for numbers of identical items.

CITATION: Ergonomics, 1959, 2, 247-253.

RATIONALE: The spatial layout which is best for a small number of similar items on a panel may not be best when extended to a large number of items. The study involved finding a layout requiring minimal panel size to accommodate 24 potentiometers and switches with easiest operation and least operator error. The operation sequence included finding and operating the switch, finding the potentiometer, adjusting the potentiometer, and turning off the switch.

METHODOLOGY:

SAMPLE SIZE: Ten subjects were used.

PROCEDURES: The study used static 2-dimensional layouts of 4 possible designs. Subjects were told to close their eyes. The experimenter would call out a number and the subject would respond by opening his eyes and tapping the switch and potentiometer of the corresponding number. The response was timed and errors were recorded.

SIGNIFICANT RESULTS: A layout utilizing 12 staggered rows of (2) potentiometers with the two switches labelled under each row proved the easiest and least confusing panel.

CONCLUSIONS/RECOMMENDATIONS:

(1) For a small number of items, a layout following the common reading pattern seems best.

(2) For a large number of items, a layout which combines the common reading pattern for the first selection and an arrangement which makes the second selection follow as uniformly and straightforward as possible seems best.

CATEGORY: SEAT DESIGN

AUTHORS: Slechta, R. F., Wade, E. A., Carter, W. K., & Forrest, J.

TITLE: Comparative Evaluation of Aircraft Seating Accommodation.

CITATION: Wright Air Development Center, 1957, WADC Technical Report 57-136.

RATIONALE: Inadequate seating accommodation is one of the many factors which can contribute to the development of pilot and crew fatigue during flights of long duration. Therefore, any research program which is concerned with the optimization of conditions for the maintenance of pilot crew efficiency must necessarily include studies of seating comfort. This paper reports basic information about the nature and progression of seating discomfort.

METHODOLOGY

SAMPLE SIZE: Eighteen subjects were used.

POPULATION CHARACTERISTICS: The subjects were selected on the bases of size from Tufts University student body and from laboratory personnel. The subject's dimensions ranged in height from 64 to 75 in., weight from 126 to 206 lbs., and in age from 18 to 33 years.

PROCEDURE: Subjects were required to sit in the seats for periods of up to 7 hours. A series of behavioral and questionnaire methods were used and tested as evaluation procedures. The dependent variables included:
(1) Sitting time.
(2) Rating scale - Intolerable discomfort/Neutral/Ideal comfort.
(3) Hourly evaluation of the degree of comfort provided by the seat.
(4) Hourly progression of specific body discomfort.
(5) Time onset of discomfort.
(6) Evaluation of seat parts.
(7) Final evaluation - frequency of suggestions.
(8) Anthropometrics and seat part evaluations.

APPARATUS: Six seats were used. Five of the seats were representative of pilot and crew seating accommodations currently provided in operational transport aircraft. The other seat (control) was made of plywood. The five seats consisted of:
(1) C-97A; KC-97E, Pilot seat (Long Range) (Weber).
(2) C-124A, Pilot seat (Gravity Load) (Weber).
(3) C-124A, Crew seat (Hardman Model 505).
(4) C-124 Crew seat (Weber).
(5) C-118 Pilot seat (Aerotherm).

SIGNIFICANT RESULTS: It was found that the sooner discomfort began, the greater discomfort tended to be. Discomfort in the buttocks and back most directly influenced the ranking of seats. Discomfort of thighs was of little importance in all except one of the seats, and could not be used in ranking the seats. Discomfort in the neck, shoulders and lower legs was negligible and had little influence on the ranking of seats. The average time of onset discomfort was a useful means of ranking the seats.

CONCLUSIONS/RECOMMENDATIONS: Comfort is a qualitative experience that admittedly is difficult to assess. The greatest amounts of discomfort were experienced in the back and buttocks and these conditions influenced seat evaluations. Lack of seat adjustability contributed to back discomfort as well as did the particular magnitudes of back angles present in seats having fixed backs. Improper seat cushioning also contributed to back discomfort. Discomfort in buttocks was highly influenced by the cushioning. Cushions too soft may be very nearly as detrimental to comfort as no cushions at all. Although head-rests seemed to have little to do with neck comfort, the presence of arm-rests and/or seat back adjustability were important factors. Discomfort in thighs was caused mainly by poorly designed thigh pads and excessively short seat cushions. Discomfort in the shoulders was influenced mainly by adjustability of the seats, while discomfort in the lower legs was associated with factors producing thigh discomfort. The data were analyzed to determine whether there were any correlations between complaints concerning seat dimensions and categories of subjects determined by body measurements, but no consistent correlations were revealed. The assumption that adequacy of seat dimensions does not necessarily assure comfort, but many other factors are involved, is supported.

CATEGORY: ANTHROPOMETRY, SEAT DESIGN, AND REACH ENVELOPE

AUTHOR: Snyder, R. G., Chaffin, D. B., & Schutz, R. K.

TITLE: Joint range of motion and mobility of the human torso.

CITATION: SAE REPORT 710848 Proceedings of the Fifteenth Stapp Car Crash Conference, New York: Society of Automotive Engineers, 1971, p. 13-41.

RATIONALE: The purpose of the study was to develop a quantitative description of the mobility of the human torso, including the shoulder girdle, neck, thoracic and lumbar vertebral column, and pelvis. The experimenters used prediction equations and graphs to describe how the base of the spine reference point (fifth lumbar spinal marker) moves in relation to defined seating and standing reference points for given reaches.

METHODOLOGY:

SAMPLE SIZE: Twenty-eight males were used.

POPULATION CHARACTERISTICS: The sample was representative of the 1967 USAF anthropometric survey by height, weight, and sitting height.

CLOTHING: Clothing worn was a jock strap or equivalent.

PROCEDURES:
(1) Cadaver to check surface to bone structure landmark relationships (very high correlation).
(2) Used 35 landmarks and took 72 measurements.
(3) The Heath-Carter technique was used to determine body somatotype.
(4) Photogrammetry was used to study body positions (35) - landmarks identified by .5 in. black tubular markers on 20 subjects.
(5) The subject was asked to reach out and touch a dull stylus target with the medial/posterior aspect of his elbow which was referenced with an inkdot.
(6) Forty-eight seated positions were used as well as 22 standing positions.
(7) Data was analyzed by touching reference points on the photographs with a cursor which allowed a data-coder to analyze the coordinates.
(8) Predictive equations
   (a) Major anthropometric variables used were sitting and standing heights.
   (b) Torso prediction models gave a good representation of torso mobility in relation to elbow positions.

Radiographic studies:
(1) Twenty-two subjects were used with 9 x-ray plates per subject. A total of 84 body configurations were used.
(2) Subjects were put in the elbow position and then the x-ray was taken.

APPARATUS:

(1) In the photogrammetry four orthogonal cameras were used - above, behind, in front, and to the side of the subject. Front and rear cameras were 35 ft. from the origin; the side and above cameras were 15 ft. from the origin. All shuttered simultaneously.

(2) The Radiographic method used a Piker KM 200 Centurian II 300 ma at 125 kv x-ray generator and a motor driven x-ray table. The table was put in a vertical position and a fixture referenced elbow positions. Data reduction used a data coder and computer.

SIGNIFICANT RESULTS:

(1) Predictive model determining the whole torso mobility was derived.

(2) Predictive model that depicts the coordinates of each surface marker as a function of the elbow position was derived.

(3) This study has provided the means for developing new techniques for the study of human torso mobility and may be of value in the design of anthropometric dummies.

CONCLUSIONS/RECOMMENDATIONS:

From inspection of the resulting graphs, one can determine the the torso configuration of a seated or standing person whose right arm is required to be in various positions.

CATEGORY: REACH ENVELOPE

AUTHOR: Stoudt, H. W.

TITLE: Arm lengths and arm reaches: Some interrelationships of structural and functional body dimensions.

CITATION: American Journal of Physical Anthropology, 1973, 38, 151-162.

RATIONALE: The purpose of the study was to develop a mehtodology to predict functional arm reaches from a battery of easily obtainable structural measurements. More specifically, the experiment was concerned with providing data to assist in establishing the outer permissible limits for the location of controls in motor vehicles.

METHODOLOGY:

SAMPLE SIZE: Data were obtained on 100 subjects, 50 males and 50 females.

POPULATION CHARACTERISTICS: Subjects were selected to approximate the distribution of the general adult driving population in height and weight as determined by the National Health Examination Survey (Stoudt, et. al., 1965).

PROCEDURES: Preliminary anthropometric measurements were taken on the subjects. These included height, sitting height, shoulder height, shoulder (biacromial) breadth, anterior arm length, elbow-fingertip length, and shoulder-elbow length. In addition, weight, age, and handedness of each subject were recorded as was the preferred fore-and-aft seat adjustment. Reach measurements (to the thumbtip) were taken for 12 vertical planes: 0^{o} (midsagittal plane), and 10^{o}, 20^{o}, 30^{o}, 40^{o}, and 50^{o} to the right and left; in addition, 70^{o} and 90^{o} to the right were included. The horizontal planes which intersected these vertical ones were at 4 inch intervals from 6 inches above the floor to 42 inches above the floor for a total of 10 horizontal planes. The subject was seated in a normal position with a lap belt tightened and a shoulder harness adjusted with exactly four inches of slack. The measurements were then taken and photographed from the side with a 35 mm. camera equipped with a 250 exposure power-operated film transport. Data was reduced using a Grafacon electronic tablet and an electronic stylus interfaced with a PDP-8/S computer. The reference point in the data slides corresponded to the hinge point of the hip and thigh.

APPARATUS: Apparatus consisted of a seat which pivoted about a vertical axis through the measuring reference point so as to attain various reach angles to the right or left. In addition, a vertical bar rolled freely back and forth along two horizontal bars positioned directly over the seat. The bottom of this bar was vertically adjustable to each of the desired horizontal planes on which the measurements were made.

SIGNIFICANT RESULTS: Correlation coefficients were calculated for the 9 structural anthropometric variables plus age, and a selected group of 24 of the more critical, or useful, functional reach dimensions. The authors found the following results:

(1) Age is very poorly if at all related to reach capability.
(2) Correlations between weight and the 117 reach measurements (3 were eliminated because subjects were unable to reach them) were only moderate, ranging between .2 and .5 and averaging around .4.
(3) Height was correlated somewhat better varying between .5 and .7 (average= over .6).
(4) Anterior arm length showed uniformly high correlations with functional reach (range= .5 to .7, average= over .6).
(5) Elbow-fingertip length showed, overall, probably the highest general correlation (.6 to .7).
(6) Shoulder-elbow height was similar to but somewhat lower than elbow-fingertip length in correlation with functional reach.
(7) Sitting height erect correlations ranged from .4 to .7 and shoulder height correlations were somewhat lower (.4 to .6).
(8) Shoulder breadth (biacromial diameter) had the lowest correlations with the exceptions of weight. Correlations ranged from .3 to .5.

To determine the predictive value of the anthropometric measurements for dynamic measurements, the eight static dimensions were included in a regression analysis with a selected group of functional arm reach measurements. Two measurements consistently emerged as superior for predictive purposes. These were elbow-fingertip length and shoulder-elbow length. These variables predict the average (roughly, the 50th percentile) reaches measured from the reference point to the outstretched hand. The equations predict less accurately at the extremes of the reach distributions (i.e. the 5th and 95th percentiles).

CONCLUSIONS/RECOMMENDATIONS:

(1) Functional arm reaches can be predicted from as few as two structural body measurements with a degree of accuracy that should be satisfactory for most design problems involving control location and workspace layout.
(2) What is needed now is a mathematical model of human reaching behavior which will take into account the effects of changes in any relevant worspace variable and, in conjunction with limited structural anthropometric data, generate the desired functional reach dimensions.

CATEGORY: ANTHROPOMETRY

AUTHORS: Stoudt, H. W., Damon, A., McFarland, R. A., and Roberts, J.

TITLE: Weight, height and selected body dimensions of adults: U. S., 1960-62.

CITATION: National Health Survey, Washington, D.C., U. S. Public Health Service, 1965.

RATIONALE: The paper describes the general population with respect to height, weight and 10 other measurements.

METHODOLOGY

SAMPLE SIZE: There were 6,672 subjects (3,091 males and 3,581 females).

POPULATION CHARACTERISTICS: Subjects were selected to represent racially, geographically, and socioeconomically the nonmilitary and noninstitutionalized American population between the ages of 18 and 79.

PROCEDURES: Subjects were selected as follows: the entire population was first stratified by broad geographic region and by size of place of residence (rural areas, small cities, etc). These strata were then subdivided into segments and households, and these units were then randomly sampled until a total of 7,700 subjects were obtained. Out of 7,700, 6,672 were actually measured. Twelve measurements were taken.

SIGNIFICANT RESULTS:

Measurement (Group)		1st	5th	50th	95th	99th
Weight in lbs.	(males)	110	124	164	215	239
	(females)	91	102	135	197	234
Stature in in.	(males)	61.7	63.7	68.3	72.8	74.6
	(females)	57.1	59.0	62.9	67.1	68.8
Sitting height in in						
	(males) erect	31.9	33.2	35.7	38.0	38.0
	(females) erect	29.5	30.9	33.4	35.7	36.6
	(males) normal slump	30.4	31.6	34.1	36.6	37.6
	(females) normal slump	28.2	29.6	32.3	34.7	35.7
Elbow rest height in in.						
(sitting)	(males)	6.3	7.4	9.5	11.6	12.5
	(females)	6.1	7.1	9.2	11.0	11.9
Thigh clearance height in in.						
(sitting)	(males)	4.1	4.3	5.7	6.9	7.7
	(females)	3.8	4.1	5.4	6.9	7.7
Knee height sitting in in.						
	(males)	18.3	19.3	21.4	23.4	24.1
	(females)	17.1	17.9	19.6	21.5	22.4
Popliteal height sitting in in.	(males)	14.9	15.5	17.3	19.3	20.0
	(females)	13.1	14.0	15.7	17.5	18.0

Measurement (Group)		1st	5th	50th	95th	99th
Buttock-knee length in in.						
	(males)	20.3	21.3	23.3	25.2	26.3
	(females)	19.5	20.4	22.4	24.6	25.7
Buttock-popliteal length in in.	(males)	16.5	17.3	19.5	21.6	22.7
	(females)	16.1	17.0	18.1	21.0	22.0
Hip breadth in in. (sitting)						
	(males)	11.5	12.2	14.0	15.9	17.0
	(females)	11.7	12.3	14.3	17.1	18.8
Elbow-to-elbow breadth in in. (sitting)	(males)	13.0	13.7	16.5	19.9	21.4
	(females)	11.4	12.3	15.1	19.3	21.2

CATEGORY: SEAT DESIGN, CONSOLE DESIGN AND WORKPLACE DESIGN

AUTHORS: Van Cott, H.P., & Kinkade, R.G.

TITLE: Human Engineering Guide to Equipment Design.

CITATION: Washington, D.C.: U.S. Government Printing Office, 1972.

RATIONALE: Representative workplace layouts should accomodate a 5th-to-95th-percentile user population. Operator-related dimensional factors that influence workplace configuration are: (1) Eye position with respect to display area and/or field of view; (2) Reach envelope of arms and legs; and (3) Manner and position of human body support. Large operator dimensions should define clearance requirements, while those of smaller operators should define reach requirements.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The critical dimensional factors in developing the seated operator station include:
(1) Proper eye position relative to the viewing tasks, either on the console or the surrounding environment.
(2) Seat height, depth, and back angle with proper posture control.
(3) Leg and knee clearance.
(4) Hand and/or foot reach requirements for control actions.
(5) A common eye position for large and small operators by means of an adjustable seat height.

A properly designed seat contributes to efficiency and safety. It must provide: (1) accessibility to the task, (2) proper support, (3) security and protection, (4) accessibility, and (5) comfort. A range of adjustment may be necessary to place the operator in proper working position. These adjustments include (1) seat height, (2) rotation, (3) fore/aft movement, (4) seat/backrest angle, and (5) lateral movement. Types and ranges of adjustable seats should be established at the same time other workplace dimensions are being developed. The recommended seat dimensions are as follows:
(1) Seat height should be adjustable between 15-18 in.
(2) Seat depth should be approximately 12-15 in.
(3) Seat width should be approximately 15-18 in.
(4) Seat pan slope should be 3°-5°.
(5) Height of backrest should be 6-8 in.
(6) Space between backrest and seat pan should be adjustable at least 4 in.
(7) Backrest width should be 12-14 in.
(8) Backrest swivel should be 10°-20°.

(9) Arm rest height should be 9 in., or have a range of 7-9 in.
(10) Arm rest length should be 10 in.
(11) Backrest should have a curvature depth of 2 in.

The recommended workplace dimensions and general layout are as follows:

(1) When panel space requirements exceed 40 in., in width, a "wrap-around" console would place all controls within reach. Left and right segments should be positioned at an angle of 110° in front of the central segment.
(2) Leg room clearance depth should be a minimum of 16 in.
(3) Foot room depth should be 24 in. (minimum) as measured from front of desk to objects in front of foot.
(4) There should be a minimum of 26 in. from the back of the seat to objects in front of the knee.
(5) The maximum placement of controls should be 28 in.
(6) Minimum leg height clearance should be 25 in.
(7) The writing desk height should be approximately 26-31 in.
(8) The maximum console height to see over top is 47 in.
(9) The minimum console height to avoid seeing top is 54 in.
(10) The console width should have a minimum value of 18 in. and a maximum value of 40 in.
(11) There should be 19 in. between arm rests.
(12) A recommended minimum surface for precise control of writing, drawing or plotting is 24 in. wide by 16 in. deep.

The recommended dimensions are based on the 5th-to-95th-percentile operators.

CATEGORY: SEAT DESIGN

AUTHORS: Wachsler, R.A. & Learner, D.B.

TITLE: An analysis of some factors influencing seat comfort.

CITATION: Ergonomics, 1960, 3, 315-320.

RATIONALE: The paper describes the factor structure of several criteria of seat comfort or discomfort. Data for the study was taken from the study by Slechta, et.al. (1957).

METHODOLOGY:

SAMPLE SIZE: Eighteen subjects were used.

PROCEDURES: Subjects were allowed to study but no writing and no conversation were allowed, except with test monitor. Five criteria were employed.

(1) Total voluntary sitting time (up to 7 hrs.).
(2) Comfort rating after 5 min. and at hourly intervals. The 9 pt. scale ranged from -4 to +4.
(3) Subject's own prediction of total sitting time. Predictions were taken after the first 5 min. and at hourly intervals.
(4) Time of onset of discomfort.
(5) Subject's comfort rating in a post-test questionnaire. The 21 pt. scale ranged from -10 to +10.

Also included was an average discomfort rating in specific body parts. The rating was taken after the first 5 min. and at hourly intervals. The 6-point scale ranged from none to intolerable. The specific body parts included the neck, shoulders, back, buttocks, thighs and legs.

APPARATUS: Six seats were employed.

(1) Seat 1 - (Long Range) Provided arm rests, head-rest, adjustment of fore and aft and vertical position and discrete adjustment of the included angle between the seatpan and seatback.
(2) Seat 2 - (Gravity Load) Same features as seat 1 but a wider range of adjustments.
(3) Seat 3 - (Control) Constructed of uncontoured plywood, no cushioning, or adjustability.
(4) Seat 4 - (Hardman, Model 605) No armrests or angular adjustments.
(5) Seat 5 - (Weber) No armrests or angular adjustments.
(6) Seat 6 - (Aerotherm) Provided arm rests, fore and aft and vertical adjustments and independent adjustment of seat pan angle and seat back angle.

SIGNIFICANT RESULTS: Two orthogonal (independent) factors were found.

(1) Factor I included the overall comfort since it had high loadings of the two general comfort measures (total sitting time and post-test questionnaire). It also had high loadings from back and buttock comfort and moderate loadings on neck and shoulder comfort.

(2) Factor II included high loadings for comfort in the thighs and in the legs. A high correlation between 5-min. ratings and total sitting time was also found.

CONCLUSIONS/RECOMMENDATIONS:

(1) People tend to rate the overall comfort of a seat mainly on the basis of the comfort of their backs and buttocks. The comfort of the neck and shoulders plays a secondary role, while thigh and leg comfort seems to have little relationship to judgements of the overall comfort of a seat.

(2) The paper concludes that one can predict fairly long term effects of sitting on a seat on the basis of a relatively short time sample (5-min.).

CATEGORY: SEAT DESIGN

AUTHOR: Washburn, C.T.

TITLE: Stadium seating.

CITATION: Architectural Record, 1932, 71, 270-272.

RATIONALE: The paper sets forth general considerations for the design of stadium seating.

METHODOLODY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Adequate seat width should not be less than 17 in.

(2) Fifteen inches should be allowed for the spectator's knees and for the passage of entering spectators.

(3) The seat height of 18 in. should be satisfactory because it gives more toe room to spectators behind the row and also because spectators sitting in an upright position take up less room horizontally.

(4) Seats are more comfortable with backs than without backs.

CATEGORY: SEAT DESIGN

AUTHORS: Weddell, G. & Darcus, H.D.

TITLE: Some Anatomical Problems in Naval Warfare.

CITATION: British Journal of Industrial Medicine, 1947, 4, 77-83.

RATIONALE: The purpose of this study was to design a seat capable of fitting all Ss with the minimum of adjustment.

METHODOLOGY:

SAMPLE SIZE: Calculations for dimensions of the seat were based on the American Fort Knox survey of body measurements of military personnel. In addition, 50 subjects were used.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) For body stabilization, it is necessary to have a seat with an adjustable foot rest so that in different individuals a knee-angle of 160° can be obtained.
(2) The seat cushion should be at least 15 in. wide and 18 in. deep. The front 8 in. should be sloped at an angle of about 10° to the horizontal, and the back 10 in. disposed horizontally when the thighs are horizontal and the knees are at an angle of 160°.
(3) The back rest optimum height should correspond to the level of the maximum concavity of the lumbar curvature (heighth should vary between 8 in. and 12 in.). The back rest should be placed 0.5 in. behind the back of the seat. The back rest should have a radius of 7.3 in. and a width of 15 in.
(4) The foot rest should be 14 in. long and 15 in. wide. A heel rest should be provided at right angles to the footrest and be at least 3 in. deep.

CATEGORY: ANTHROPOMETRY

AUTHORS: White, R. M., & Churchill, E.

TITLE: The Body Size of Soldiers: U. S. Army Anthropometry-1966.

CITATION: Technical Report 72-51-CE, Natick, Massachusetts, U. S. Army Natick Laboratories, 1971.

RATIONALE: Seventy body measurements were taken from 6682 Army men. Changes in the body size of Army men between 1946 and 1966 are discussed.

METHODOLOGY

SAMPLE SIZE: Subjects were 6682 males.

POPULATION CHARACTERISTICS: The subjects were measured at 12 Army posts throughout the U. S.

PROCEDURES: Seventy body measurements were selected.

APPARATUS: The apparatus included an Anthropomenter (Siber Hegner 101), small sliding calibers (Siber Hegner 104), spreading calibers (Siber Hegner 106), and a two-meter steel tape.

SIGNIFICANT RESULTS:

Measurement	Mean	S. D.
Age	22.17 yrs.	4.64
Weight	159.10 lbs.	23.35
Stature	174.52 cm.	6.61
Shoulder height	143.72 cm.	6.22
Functional reach (standing)	82.60 cm.	4.85
Vertical Arm reach (sitting)	138.23 cm.	5.80
Sitting height	90.69 cm.	3.66
Eye height (sitting)	78.72 cm.	3.57
Shoulder-elbow length	36.87 cm.	1.86
Elbow-fingertip length	47.96 cm.	2.31
Knee height (sitting)	54.06 cm.	2.73
Popliteal height (sitting)	44.61 cm.	2.50
Buttock-knee length	59.47 cm.	2.85
Buttock-popliteal length	49.82 cm.	2.50
Forearm-forearm breadth	45.98 cm.	4.22
Hip breadth (sitting)	34.16 cm.	2.38

CONCLUSIONS/RECOMMENDATIONS: The changes in body dimensions of Army men between 1946 and 1966 actually, are rather small, at least with respect to the mean (or average) values. There has been an increase of 4.25 lbs. in mean weight and mean stature has increased 0.25 in. in Army men between 1946 and 1966. Most of the standing and sitting measurements are slightly higher for the 1966 Army series.

CATEGORY: SEAT DESIGN, CONSOLE DESIGN, AND WORKPLACE DESIGN

AUTHORS: Woodson, W. E. & Conover, D. W.

TITLE: Human Engineering Guide for Equipment Design.

CITATION: Berkeley, California: University of California Press, 1964.

RATIONALE: The workplace envelope must be compatible with the anthropometric dimensions of the particular population of workers who will be using the proposed equipment. This book reviews the recommendations for dimensions of equipment. Proper seat design can reduce fatigue and promote increased production by its occupant; it can save time and energy. Poor seating may be the cause of poor morale and may actually interfere with optimum operations of equipment and cut down the efficiency of an operator.

METHODOLOGY: N/A

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: Rules for console design:

(1) Controls and displays which are to be used most often, most effectively, or most rapidly should be given first priority as to location on the panel or console.

(2) Visual displays should be oriented so that parallax and glare are minimum and viewing distance and illumination are optimum.

(3) The size of the instrument panel depends primarily upon the normal arm reach of the human operator. In general, convenient arm reach is about 28 in. from the respective shoulder pivot point.

(4) In a U-shaped console, the front section of the console should be approximately 44 in. in order to allow the operator to reach the corners of the console.

Rules for Work Space:

(1) Effective work-seat design should provide a supporting framework for the body relative to the activity in which it is engaged.

(2) The seat should be convenient to the task of the worker. The seat should be of proper size and should be adjustable not only in height but in position when the application demands mobility.

(3) The seat should support the body properly to avoid poor posture. Cushioning should be used to distribute body weight evenly over the surface of the seat.

(4) Arm rests should be provided when they do not interfere with the individual task at hand. Foot rests should be provided to maintain optimum seat-to-foot rest distance.

Dimensions for a secretarial chair should be:

(1) Seat Height - 15 to 18 in. (adjustable).
(2) Seat Width - 15 in.
(3) Seat Depth - 12 to 15 in.
(4) Seat Pan Slope - 3 to 5^{o}.
(5) Space between Seat and Backrest - 7 to 10 in.
(6) Height of Backrest - 6 to 8 in.
(7) Backrest Angle - 90 to 110^{o}.
(8) Backrest Curvature Depth - 2 in.
(9) Backrest width - 12 to 14 in.

Dimensions for Special Operator Chair, recommended for activities such as sonar, radar air traffic control, etc.:

(1) Seat Height- 16 to 18 in.
(2) Seat Pan Slope - 3 to 5^{o}.
(3) Seat Depth - 15 to 17 in.
(4) Seat Width - 18 in. (minimum).
(5) Space between Seat and Backrest - 5 in.
(6) Height of Backrest - 12 in.
(7) Backrest Angle - 97 to 109^{o}.
(8) Backrest Width - 15 in.
(9) Backrest Curvature Depth - 2 in.
(10) Arm Rest Height - 9 in.
(11) Arm Rest Length - 10 in.
(12) Arm Rest Depth - 2 in.

Rules for desks, tables, counters, and workbenches:

(1) Thigh Clearance - 7 in. (minimum).
(2) Height of Work Surface - 29 to 30 in.
(3) Knee Depth from Beginning of Work Surface to Obstructions in Front of the Knees - 16 in.

CATEGORY: SEAT DESIGN

AUTHORS: Wotzka, G., Grandjean, E., Burandt, U., Kretzschmar, H., and Leonhard, T.

TITLE: Investigations for the development of an auditorium seat.

CITATION: Ergonomics, 1969, 12, 182-197.

RATIONALE: An orthopaedically proper seat is designed to avoid unnatural postures. Unnatural postures are accompanied by pain and symptoms of fatigue, amd are felt to be uncomfortable. This led to the conclusion that a seat profile is desirable which causes the least possible discomfort and pain to as many persons as possible. Apart from the orthopaedic recommendations, the functions of an auditorium seat were also considered. The first stage of the experiment consisted of analyzing the seated behavior of 546 students during lectures by means of the multi-moment technique, along with assessment by students. It was found that the table top surfaces were felt to be too small by the majority in all auditoriums (dimensions ranged from 30x57 cm. and 30x60 cm.). Leg room was said to be unsatisfactory by the majority. A seat depth of 38 cm. was frequently thought inadequate, 42 to 44 cm. deep was judged significantly better.

METHODOLOGY:

POPULATION CHARACTERISTICS:

1st Stage - 546 students were observed using a multi-moment technique

2nd Stage - 27 male and 3 female students (average age 22.6 yrs.) were used.

Height with shoes Mean 177.4 S.D. 6.9 cm.

For 20-30 minutes, the relationship between back, seat surface, seat height, and writing surface was adjusted until the Ss stated that the most comfortable posture had been achieved. Ss then answered a questionnaire.

3rd Stage - 36 males and 4 females (average age 23 yrs.) were used.

Height with shoes Mean 178 cm. S.D. 7 cm.

Pair comparisons between seats were used.

4th Stage - Tests were made during regular lectures. Students completed the questionnaire at the end of the lecture.

APPARATUS: 5 seats, adjustable in the correlation between seat surface and back, were used. Seats were in front of a writing table (surface measured 40x80 cm.) which could be adjusted for height and inclination.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS:

(1) Seat heights of 43 to 44 cm. are somewhat too low for students.

(2) The inclination of the seat surface of 15° is considered to be good.

(3) The seat depth of 43 to 44 cm. of all seats is largely described as good.

(4) The inclination of the writing surface was modified to 10°.

(5) The seat which was selected as the best seat had the following dimensions:

- (a) width of seat - 500 mm.
- (b) width of back rest - 500 mm.
- (c) curvature radius of backrest - 800 mm.
- (d) seat depth - 440 mm.
- (e) seat slope - 15° rearward declination but it then slopes up in the back.
- (f) back rest slope - 108°
- (g) seat to writing desk - 280 mm.

CATEGORY: WORKPLACE DESIGN

AUTHOR: Yllo, A.

TITLE: The bio-technology of card punching.

CITATION: Ergonomics, 1962, 5, 75-79.

RATIONALE: This paper describes a practical application of bio-technology at Volvo. The investigation was carried out in connection with improvements concerning the efficiency of the methods of work of six female punch-machine operators.

METHODOLOGY:

SAMPLE SIZE: Six subjects were used.

POPULATION CHARACTERISTICS: All subjects were female punch-machine operators.

APPARATUS: The standard IBM punch machine, type 24, was employed.

SIGNIFICANT RESULTS: N/A

CONCLUSIONS/RECOMMENDATIONS: The deficiencies of the design of the machine were as follows:

(1) The keyboard was too high in relation to the working arm. This position placed the right elbow at too sharp an angle. The operator tried to compensate for this fault by lifting up the shoulder or by moving the elbow out in a lateral direction so that the working fingers were placed improperly relative to the keyboard. This arm position causes excessive static muscle activity in the neck, shoulder, and arm.

(2) The original keyboard position forces the hand to work with the forearm twisted almost the maximum to the thumb side.

(3) The keyboard was relatively fixed causing an unnatural wrist position.

(4) The sight distance from eye to the moving card in the machine was too great, approximately 60 to 65 cm.

SECTION B

SEATING, CONSOLE, AND WORKPLACE DESIGN:
An Integration of the Literature

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SECTION B

CONTENTS

CONTENTS (Concluded)

SUMMARY

The purposes of Section B are (1) to review, discuss, and integrate the requirements of seat, console, and workplace design of the seated operator; and (2) to provide the recommendations for seat, console, and workplace design in terms of design dimensions and design characteristics.

Detailed aspects of these components and their relationship to each other in making up the workplace are discussed. Basic recommendations about the seat, console, and workspace needed for the operator are made.

INTRODUCTION

It is well known that the seated operator has a number of advantages over the standing operator (Ayoub, 1971; Kroemer, 1971) including:

1. Sitting requires less muscular activities for maintaining posture. Therefore, the seated operator can avoid or delay the onset of fatigue.
2. Sitting provides more stability in body positions. The stability is valuable for tasks which require precision or fine manipulative movements and visual fixation.
3. Sitting provides for easier operation of foot controls.
4. Sitting results in lower intravascular pressure in the lower extremities.

When designing the console/workplace for a seated operator, the operator should be considered at the beginning of the design. The Human Engineering Design Criteria for Military Systems, Equipment and Facilities (DoD, 1975) states that "chairs to be used with 'sit' consoles shall be designed to be operationally compatible with the console configuration" (p. 116). If, as is usually the case, the operator is not considered at the beginning of the console/workplace design, the operator, as a direct consequence of the faulty design, may be forced into awkward and inefficient body positions. The poor posture exhibited by an operator forced to work under the constraints of the faulty design, can lead to low productivity, fatigue, and even injury (Ayoub, 1971). It has been noted that the seat design and the console/workplace design cannot be considered independently. According to Floyd and Roberts (1958) and McCormick (1970), when seats are to be used in combination with desks or tables (i.e., workplace), the dimensions of the two must be worked out together. Therefore, the seat and console/ workplace should be designed as a unit with the dimensions of one dependent on the dimensions of the other (Kroemer, 1971).

Purpose

The purposes of this report are:

(1) To review, discuss and integrate the requirements of seat, console, and workplace design of the seated operator.

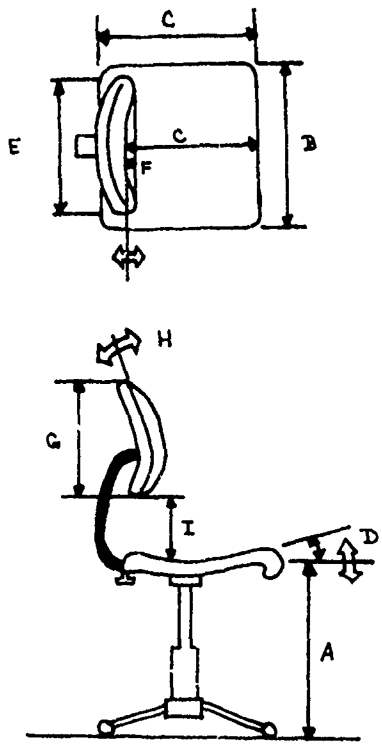
(2) To provide recommendations for seat and console/workplace design, in terms of design dimensions and design characteristics.

SEAT PAN DESIGN

The main design features of an adjustable chair are presented in figure B-1. These features include the following dimensions: (a) seat pan height; (b) seat pan width; (c) seat pan depth; (d) seat pan slope; (e) backrest width; (f) curvature of the backrest; (g) backrest height; (h) backrest swivel: and (i) the space between the seat pan and the backrest. Table B-1 contains the shape and dimensions of the seat pan surface as proposed in the literature. A summary of the discussion and recommendations for the shape and dimensions of the seat pan are presented in table B-2.

Shape of seat pan

One of the important features of a good chair is that it permits the user to change his posture with ease (Äkerblom, 1954). According to Floyd and Roberts (1958), changes in posture can be extremely important in relieving muscle fatigue. Generally, no shaping is



A. Seat pan height
B. Seat pan width (breadth)
C. Seat pan depth
D. Seat pan slope
E. Backrest width
F. Curvature of the backrest
G. Backrest height
H. Backrest swivel and backrest angle
I. Space between seat pan and backrest

Figure B-1. Main Design Features of an Adjustable Chair.

Table B-1. Proposed Shape and Dimensions of the Seat Pan Surface

Dimension	Reference	Recommendation	Remarks
Shape of the seat pan	Ayoub, M.M. (1971)		Although in some cases profiles of seat pans are desirable, generally no shaping is recommended for industrial or office chairs. The seat front should be round (scrolled) to eliminate pressure in the popliteal area.
	Croney, J. (1971)		For short-period sitting, a seat surface can be completely firm, provided space is left for shifting the body position. Allowance for adjustment of position delays fatigue in sitting. Sculptured seat surfaces can only expect limited use. A rounded seat front edge should be provided.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)		Generally, seats should be flat rather than shaped because of the varied configurations of the human buttocks and perineal region. Nevertheless, cutouts or depressions under the ischial tuberosities are more comfortable and efficient than flat seats.
	Darcus, H.D., & Weddell, A.G.M. (1947); Weddell, A.G.M., & Darcus, H.D. (1947)		The front edge of the seat should be softly sprung to prevent undue pressure on the underside of the thigh.
	Floyd, W.F., & Roberts, D.F. (1958)		The seat should be substantially plane.
	Grandjean, E., Hunting, W., Wotzka, G., & Scharer, R. (1973)		A gently-molded seat surface which is flat in front under the thighs and slants upwards in the back under the buttocks is recommended.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
	Karvonen, M.J., Koskela, A., & Noro, L. (1962)		The front edge should be bent down or rounded so that it does not press on the underside of the thigh. The seat should be smooth and not molded to conform to the buttocks.
	Keegan, J.J. (1953, 1962)		The front border of the seat should be curved downward or should be upholstered to aid in molding the thighs over the edge of the seat so that the feet can reach the floor.
	Kroemer, K.H.E. (1971); Kroemer, K.H.E., & Robinette, J.C. (1968)		The seat pan should be essentially plane, only slightly concave (less than 2 cm.) in the center part. There should be no hard or sharp edges. The front edge should be rounded with a radius of at least 2.5 cm.
	McFarland, R.A., Damon, A., Stoudt, H.W., Moseley, A.L., Dunlap, J.W., & Hall, W.A. (1953)		A very soft and resilient seat would transfer a large amount of the weight to tissues which are not adapted for bearing it. The best seat consistency should give only slight pressure.
	Morgan, C.T., Cook, J.S., Chapanis, A., & Lund, M.W. (1963)		Most seat pans should be flat rather than shaped, because of the difficulty of changing position in a shaped seat. If the occupant will be virtually immobile for many hours, a seat with cut-outs or depressions under the bony protuberances are more comfortable and efficient than flat seat pans.
	Murrell, K.H. (1969)		It is undesirable to shape the seat. The front edge of the seat should be curved downward.
	Nissley, H.R. (1949)		Rounded, blunt edges, and corners are better than sharp pointed edges.
	Oxford, W.F. (1969)		The seat pan should be curved slightly at the front. Dished seats and saddle seats are not recommended since they restrict movement.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
Seat pan upholstery	Ayoub, M.M. (1971)		The upholstery should be stiff and not give way any more than 1 inch. The stiff upholstery reduces pressure on the buttocks and permits change of posture.
	Branton, P. (1969)		Upholstery of the seat should not restrict the dissipation of perspiration moisture and heat.
	Croney, J. (1971)		The upholstery should have a depression of no more than 0.5 in. A depression of more than that does not allow the average ischial tuberosity to take the majority of the weight and the surrounding tissues become too compressed. Seat surfaces should not be too highly polished. A textured or rough surface is best.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)		The seat pan upholstery should have 1 to 2 inches of compression. People perform more efficiently for longer periods in soft seats - not "supersoft" but certainly cushioned - than on hard seat surfaces.
	Darcus, H.D., & Weddell, A.G.M., & Darcus, H. D. (1947)		The seat pan upholstery should be resilient. If the seat cushion is too soft, the excessive transfer of pressure to adjacent parts may cause discomfort. The resilience should be such that the variation of the degree of compression does not exceed 1 in. with persons of different body build.
	Floyd, W.F., & Roberts, D.F. (1958)		The seat should be hard in order that pressure may be concentrated over the ischial tuberosities and not distributed paraischially. The softer the seat the greater tendency for pressure to be widely distributed.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
	Grandjean, E., Hunting, W., Wotzka, G, & Scharer, R. (1973)		A padding with foam rubber of 2 to 4 cm. on the entire seat is recommended. The material should allow for circulation of air, should not be slippery, and should conserve energy.
	Keegan, J.J. (1953, 1962)		The covering of upholstered chairs should be porous and rough to provide ventilation and fixation.
	Kroemer, K.H.E. (1971); Kroemer, K.H.E., & Robinnette, J.C. (1968)		The seat pan should be upholstered stiffly. The upholstery should give not more than 2.5 cm.
	Morgan, C.T., Cook, J.S. Chapanis, A., & Lund, M.W. (1963)		The seat pan should be cushioned in which 1-2 in. of compression will suffice.
	Morrison, J.F. (1965)		The seat should not be soft or the ischial tuberosities will sink in too far and the surrounding soft tissues will be subjected to undue pain.
	Slechta, R.F., Wade, E.A., Carter, W.K., & Forrest, J. (1957)		Improper seat cushioning contributes to back discomfort. Discomfort in buttocks is highly influenced by the cushioning. Cushions too soft may be very nearly as detrimental to comfort as no cushions at all.
	Woodson, W.E., & Conover D.W. (1964)		The upholstery should provide ventilation to prevent sweating during hot, humid weather.
Seat pan slope	Akerblom, B. (1954)	5°-7° Rearward declination	
	Ayoub, M.M. (1971)	Essentially flat and concave in the center	A slight rearward slope of the entire seat pan of approximately 3° to 5° can be used. The rearward slope causes the sitter's trunk to tilt towards the backrest and at the same time prevent sliding out of the seat. The concavity will help maintain the sitter in the middle of the seat to prevent sliding.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
	Burandt, U., & Grandjean, E. (1963)	3° Rearward declination	
	Croney, J. (1971)	0°-5° Rearward declination	
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	5°-7° Rearward declination	
	Darcus, H.D., & Weddell, A.G.M. (1947); Weddell, A.G.M., & Darcus, H.D. (1947)		The front 8 in. of cushion should be sloped to an angle of 10° to the horizontal and the back 10 in. disposed horizontally.
	Floyd, W.F., & Roberts, D.F. (1958)	Horizontal or 3°-5° Rearward declination	
	Grandjean, E., Boni, A., & Kretzchmar, H. (1969)	23°-24° for reading 25°-26° for rest	Recommended for easy chairs
	Grandjean, E., Hunting, W., Wotzka, G., & Scharer, R. (1973)	7° Rearward declination	The seat pan should be of slight concavity.
	Jones, J.C. (1969)	7° Rearward declination	For automobile workspace
	Karvonen, M.J., Koskela, A., & Noro, L. (1962)		To prevent sliding the seat should slope slightly backwards.
	Keegan, J.J. (1953, 1962)	Upward inclination of 5°	To maintain the proper position against the lower lumbar back support.
	Kroemer, K.H.E. (1971)	6° above and below the horizontal	The seat pan slope should be adjustable.
	Kubokawa, C., & Woodson, W. (1969)	0°-5° Rearward declination	
	Le Carpentier, E.F. (1969)	males 9.0° females 12.0° for both 10.5°	Recommended for easy chairs.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
	McFarland, R.A., Damon, A., Stoudt, H.W., Moseley, A.L., Dunlap, J.W., & Hall, W.A. (1953)		As the backrest must be more or less vertical it can only partially support the body weight, the support given being proportional to the inclination. If the seat is horizontal, the pressure on the backrest gives rise to an opposing force which tends to push the buttocks forward. If the buttocks are to remain firmly in position the plane of the seat should lie at a right angle to the plane of the inclination of the body.
	Morgan, C.T., Cook, J.S. Chapanis, A., & Lund, M.W. (1963)	6°-7° Rearward declination	Tilting back the entire seat pan or its surface prevents the operator from sliding forward on the seat and permits the backrest to support part of the body weight.
	Morrison, J.F. (1965)	5°-7°	
	Murrell, K.H. (1969)	3°-5° Rearward declination	The rearward declination opposes the force which tends to push the user out of the seat when the seat pan is horizontal.
	Ridder, C.A. (1959)		The seat pan slope for chairs designed for writing (alert positions) should be 0.5 in. from front to back. The seat pan slope for chairs designed for talking should be .8 in. from front to back.
	SAE Standard	7° Rearward declination	Recommended for seats for flight crewmen.
	Van Cott, H.P., & Kinkade, R.G. (1972)	3°-5° Rearward declination	
	Woodson, W.E., & Conover, D.W. (1964)	3°-5°	For secretarial and special operator chairs.
	Wotzka, G., Grandjean, E., Burandt, V., Kretzschmar, H., & Leonard, T. (1969)	15° Rearward declination with an upward inclination in the very rear of the seat.	For student seats.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
Seat pan height	Akerblom, B. (1954)	40 cm.	
	Ayoub, M.M. (1971)	18 in. (fixed) 16-20 in. (adjustable)	The height of the seat should be slightly less than the popliteal height.
	Burandt, U., & Grandjean, E. (1963)	45-53 cm. 40-48 cm.	For office tables of 78 cm. high. For office tables of 70-74 cm. high.
	Croney, J. (1971)	14.5 to 18.5 in. (males) 14.0 to 17.5 in. (females)	The seat height should be adjustable.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	15-16 in.	Maximum for seats of fixed height, without footrests. Based on popliteal height sitting.
	Floyd, W.F., & Roberts, D.F. (1958)	15-19 in.	The height should be adjustable. The height of the seat should be no more than the length of the lower leg of the shortest person who will use the chair.
	Grandjean, E., Boni, A., & Kretzchmar, H. (1969)	39-40 cm. (reading) 37-38 cm. (rest)	Recommended for easy chairs.
	Grandjean, E., Hunting, W., Wotzka, G., & Scharer, R. (1973)	43 cm. 44-46 cm.	For seat surface profile that slants up in the front. The 17 in. height should be at the highest point of the part supporting the thighs. For a seat surface profile that is flat.
	Hooton, E.A. (1945)	16.9 in.	Based on popliteal height sitting.
	Jones, J.C. (1969)	12 in.	For automobile workspace.
	Keegan, J.J. (1953, 1962)	16 in. 18 in. 20 in.	If the seat depth is 16 in. If seat is used with a desk over 30 in. in height. If user is to work directly over the desk and the desk is 30 in. in height.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
	Kennedy, K.W., & Bates, Jr., C. (1965)	18 in.	From seat to heel catch on floor.
	Kocker, A.L., & Frey, A. (1932)	18 in.	
	Kroemer, K.H.E. (1971); Kroemer, K.H.E., & Robinette, J.C. (1968)	40-50 cm.	The height should be adjustable between this range. The height should be measured from the floor or foot rest. The height of the seat should be slightly less than the distance from the floor to the popliteal area of the seated person.
	Kubokawa, C., & Woodson, W. (1969)	18 in.	Adjustment should be in 2 in. increments/ decrements.
	Le Carpentier, E.F. (1969)	15.0 in. (male) 16.5 in. (female) 15.0 in. (both)	Measurement of height of seat front for easy chairs.
	McFarland, R.A., Damon, A., & Stoudt, H.A. (1958)	15 in.	Based on popliteal height sitting.
	McFarland, R.A., Damon, A., Stoudt, H.W., Moseley, A.L., Dunlap J.W., & Hall, W.A. (1953)	17 in. (males)	Seat height should correspond to the measurement from the floor to the tendons of the flexors of the knee when measured in the sitting position. The height of the chair should not exceed the length of the lower leg, without shoes.
	Morgan, C.T., Cook, J.S. Chapanis, A., & Lund, M.W. (1963)	15-16 in.	For the general-purpose seat. If forced to choose between too low and too high a seat, the lower should be chosen.
	Morrison, J.F. (1965)	38 cm. (American population)	The seat height should be 2 cm. lower than the popliteal height of those with shorter legs.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
	Murrell, K.H. (1969)	Adjustable height females: 14-17.5 in. males: 15-18.5 in. Fixed height females: 15-15.5 im. males: 16.5 in. Fixed height for both males and females: 16-16.5 in.	Based on the popliteal height and curvature of the thigh.
	Oxford, H.W. (1969)	17.5 in.	Recommended for educational chairs.
	Ridder, C.A. (1959)		The height of the chair designed for writing (alert positions) should be 16 in. at the front lowest point, 17 in. at the front at the highest point; 14.2 in. at back at the lowest point, and 16.5 in. at back at the highest point. The height of the chair designed for talking should be 15.7 in. at front at the lowest point, 16.5 in. at front at the highest point (sides); 13.5 in. at back at the lowest point, and 15.7 in. at back at highest point.
	SAE Standard	6.5-13.5 in.	Recommended for seats for flight crewmen.
	Van Cott, H.P., & Kinkade, R.G. (1972)	15-18 in.	The seat pan height should be adjustable.
	Washburn, C.T. (1932)	18 in.	For stadium seating.
	Woodson, W.E., & Conover D.W. (1964)	15-18 in. (adjustable) 16-18 in.	For secretarial chairs. For special operator chairs.
	Wotzka, G., Grandjean, E., Burandt, U., Kretzschmar, H., & Leonard, T. (1969)	45-46 cm.	For student seats.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
Seat pan width	Ayoub, M.M. (1971)	16 in.	Based on the bi-trochanteric width +25%. Width must be large enough to accommodate a large percent of the population.
	Croney, J. (1971)	17 in. (minimum)	Only the minimum allowance must be considered in terms of hip width, the spread of the buttocks and shifting of positions.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	18 in.	Based on hip breadth.
	Darcus, H.D., & Weddell, A.G.M. (1947); Weddell, A.G.M., & Darcus, H.D. (1947)	15 in.	The seat pan width should be wide enough to accommodate users of maximum dimensions, as well as allowing a certain amount of lateral movement.
	Floyd, W.F., & Roberts, D.F. (1958)	16 in. seats with armrests 19 in.	Based on trochanteric width. The minimum width is determined by the need for support of the ischial tuberosities.
	Grandjean, E., Hunting, W., Wotzka, G., & Scharer, R. (1973)	40 cm.	
	Hooton, E.A. (1945)	21.3 in.	Seat width can be reduced to 19 in. Based on hip breadth.
	Kocker, A.L., & Frey, A. (1932)	17 in.	
	Kroemer, K.H.E. (1971)	40 cm.	
	Kubokawa, C., & Woodson, W. (1969)	16 in.	

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
	McFarland, R.A., Damon, A., Stoudt, H.A. (1958)	18.8 in.	Based on seat breadth. This dimension is for a driver's workspace.
	Morgan, C.T., Cook, J.S. Chapanis, A., & Lund, M.W. (1963)	17 in. (minimum)	A reasonable seat pan width is 18 in.
	Murrell, K.H. (1969)	17 in. seats with armrests 19 in.	The seat pan width should allow movement of buttocks and should be over rather than under the bi-trochanteric width.
	Oxford, H.W. (1969)	14 in.	Recommended for educational chairs.
	Ridder, C.A. (1959)		The minimum width (if the sides are partially enclosed) should be 17 in. at the front of the seat and toward the back of the seat before the narrowing curve, which starts about 13 in. from the front of the seat.
	SAE Standard	17-18 in.	Recommended for seats for flight crewmen.
	Van Cott, H.P., & Kinkade, R.G. (1972)	15-18 in.	
	Washburn, C.T. (1932)	17 in. (minimum)	For stadium seating.
	Woodson, W.E., & Conover, D.W. (1964)	15 in. 18 in.	For secretarial chairs. For special operator chairs.
	Wotzka, G., Grandjean, E., Burandt, U., Kretzschmar, H., & Leonard, T. (1969)	500 mm.	For student seats.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
Seat pan depth	Akerblom, B. (1954)	45-47 cm.	
	Ayoub, M.M. (1971)	16 in.	A clearance of approximately 4 in. should be maintained between the seat front and the popliteal area. Seats that are too deep cause excessive pressures on the popliteal area.
	Burandt, U., & Grandjean, E. (1963)	35-40 cm.	
	Croney, J. (1971)	15 in.	
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	16-17 in.	The seat pan depth should not cut into the user's back of the knee. For greater mobility on the part of the operator, the depth can be reduced to 12 in., but a foot rest is required.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	16-17 in.	Based on the popliteal-buttock length of the shorter members of the population.
	Darcus, H.D., & Weddell, A.G.M. (1947); Weddell, A.G.M., & Darcus, H.D. (1947)	18 in.	The seat depth should be sufficient to afford light support for the thighs, but the thighs should not press heavily against the front edge of the cushion. Based on length of the underside of thigh for smallest user.
	Floyd, W.F., & Roberts, D.F. (1958)	15 in.	Based on the length of the thighs of the shortest persons using the seat.
	Grandjean, E., Hunting, W., Wotzka, G., & Scharer, R. (1973)	43 cm.	The seat depth is from the lumbo-sacral support to the front edge of the seat.
	Hooton, E.A. (1945)	20 in.	The depth of seat should be selected to provide for the fact that most individuals do not put their buttocks against the back.

Table B-1. Continued

Dimension	Reference	Recommendation	Remarks
	Jones, J.C. (1969)	17 cm.	For automobile workspace.
	Karvonen, M.J., Koskela, A., & Norc, L. (1962)	40 cm.	For school chairs.
	Keegan, J.J. (1953, 1962)	16 in.	Measured from the most prominent point of the lower lumbar support. Dimension depends on seat height, as height increases, depth decreases.
		14 in.	If seat is used with a desk over 30 in. in height and the seat is 20 in. in height.
	Kocker, A.L., & Frey, A. (1932)	16 in.	
	Kroemer, K.H.E. (1971); Kroemer, K.H.E., & Robinette, J.C. (1968)	40 cm.	The seat length must not be excessive. If the seat is too long an individual tends to sit on only the front part to avoid pressure on his thighs near the knees. Consequently, he will not use the backrest.
	Kubokawa, C., & Woodson, W. (1969)	16 in.	
	Le Carpentier, E.F. (1969)	18.5 in.	Recommended for easy chairs.
	McFarland, R.A., Damon, A., & Stoudt, H. A. (1958)	17 in.	Based on buttock to back of knee.
	McFarland, R.A., Damon, A., Stoudt, H.W., Moseley, A.L., Dunlap, J.W., & Hall, W.A. (1953)	8-10 in. 16 in.	If thighs are to be free from contact. For occasional support for the thighs plus the necessity for altering the position. The upper limit for seat depth will be set by the thigh length as measured from the back of the calf to the plane of the back in the seated position.

Table B-1. Concluded

Dimension	Reference	Recommendation	Remarks
	Morrison, J.F. (1965)	40 cm.	The depth of the seat should be no more than the length of the thigh measured from the back of the knee to the back of the sacral region.
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)	17 in.	Best for a general purpose seat. Too long a seat pan presses into the leg behind the knee, causing discomfort and possible danger, unless the sitter can shift his position forward.
	Murrell, K.H. (1969)	15-16 in.	Seat pan depth should allow the buttock to move to permit changes of posture, but should not be too deep that the seat pan cuts into the back of the knee.
	Oxford, H.W. (1969)	14.5 in.	Recommended for educational chairs.
	Ridder, C.A. (1959)		The depth of the chair designed for writing (alert position) should be 16.5 in. from front to back and 11.5 in. from front to point of lowest depression. The depth of the chair designed for talking should be 17.5 in. from front to back and 13.5 in. from front to point of lowest depression.
	SAE Standard	16-17.5 in.	Recommended for seats for flight crewmen.
	Van Cott, H.P., & Kirkade, R.G. (1972)	15 in. (maximum)	
	Woodson, W.E., & Conover, D.W. (1964)	12-15 in. 15-17 in.	For secretarial chairs. For special operator chairs.
	Wotzka, G., Grandjean, E., Burandt, U., Kretzschmar, H., & Leonard, T. (1969)	440 mm.	For student seats.

Table B-2. Summary of the Discussion and Recommendations for the Shape and Dimensions of the Seat Pan

Dimension	Discussion	Remarks	Previous Recommendation
Shape of the seat pan	An important feature of a good chair is that the seat pan permits the changing of position/posture with ease. In addition, the seat pan front should not cause excessive pressure to the underside of the thighs.	Since there is a varied conformation of human buttocks and perineal region, no shaping of the seat pan is recommended.	The seat pan should not be shaped, although the center of the seat pan may be concave to prevent the user from sliding out of the seat. The seat pan front should be round (scrolled) or curved downward to eliminate any pressure on the popliteal area. The exposed seat pan should not have any sharp or hard edges.
Seat pan upholstery	A hard seat pan surface can lead to discomfort of the user. Contrarily, very soft upholstery is not recommended since it hinders the user when he changes positions/ posture.	A flat, stiff upholstery will reduce pressure on the buttocks and also permit changes of posture. The upholstery should afford ventilation for the user to reduce sweating.	The seat pan upholstery should be flat and stiff, not giving way more than 1 inch.

Table B-2. (cont'd.)

Summary of the Discussion and Recommendations for the Shape and Dimensions of the Seat Pan

Dimension	Discussion	Remarks	Previous Recommendation
Seat pan slope	A horizontal seat pan causes the user to slide out of the seat if he leans against the backrest. A slight rearward slope tends to tilt the user's trunk towards the backrest and to prevent the user from sliding out of the seat. On the other hand, a slight rearward slope tends to cause kyphosis of the lumbar spine when the user does not lean against the backrest.	If the seat pan slope is adjustable, it is desireable to have it slope above and below the horizontal. If the seat pan slope is not adjustable, a generally horizontal seat but slightly concave in the center will help maintain the user in the middle of the seat, preventing sliding. The concavity of the center of the seat pan also permits various changes in position.	The seat pan slope should be adjustable between 6° above and below the horizontal axis. If the seat pan slope is not adjustable and the center of the seat pan is not concave, the seat pan should slope approximately 3° to 5° rearward.
Seat pan height	The user's thighs should be horizontal when his lower legs are vertical and his feet are flat on the floor or foot rest pan. If the seat pan is too high, the user's body will slide forward and the user may not use the backrest. If the seat is too low, the user will assume a forward crouch.	The seat pan height should be slightly less than the popliteal height. The seat height should be adjustable for at least the smallest (e.g., 5th percentile) to the largest (e.g., 95th percentile) users' popliteal height	If the seat height is adjustable, it should be adjustable between 40 to 50 cm. (16 to 20 in.) above the floor or foot rest pan. If seat height is not adjustable, it should be positioned approximately 45 cm. (18 in.) above the floor or foot rest pan.

Table B-2. (Cont'd.)

Summary of the Discussion and Recommendations for the Shape and Dimensions of the Seat Pan

Dimension	Discussion	Remarks	Previous Recommendation
Seat pan width (breadth)	The seat pan width must be large enough to accomodate the largest users, as well as to facilitate changes of posture.	The seat pan width is based on the largest users' (e.g., 95th percentile) hip breadth sitting or thigh breadth (measured at the widest part of the thighs while sitting). As a result of the thigh cross-sectional curvature, the seat pan width may be reasonably 2 inches less than the largest percentile hip breadth, but arm rests and side supports must clear these dimensions. As a minimum, seat width should extend approximately 2 inches on each side beyond the center-contact points of the largest users' ischial tuberosities (boney protuberances).	The seat pan width should be approximately 40 cm. (16 in.).

Table B-2. Concluded

Summary of the Discussion and Recommendations for the Shape and Dimensions of the Seat Pan

Dimension	Discussion	Remarks	Previous Recommendation
Seat pan depth	The seat pan depth must not be excessive. If the seat pan depth is too deep, the user tends to sit only on the front part of the seat to avoid excessive pressure on the popliteal area, not being able to lean against the backrest.	The seat depth should be sized for the smallest users (e.g., 5th percentile) buttock to popliteal length, if no adjustment to the seat depth is provided. An adjustable backrest swivel allows users of different buttock to popliteal length dimensions to sit in the same seat pan, hence, a type of seat depth adjustability. If the seat depth is adjustable, the maximum seat depth (i.e., from the back edge of the seat to the front edge of the seat) should be based on the buttock to popliteal length of the largest users (e.g., 95th percentile). The minimum seat depth (i.e., from the front edge of the seat pan to the lumbosacral support) should be based on the buttock to popliteal length of the smallest (e.g., 5th percentile) users.	If the seat depth is nonadjustable, it should be approximately 40 cm. (16 in.). If an adjustable backrest swivel is used, the maximum seat depth (i.e., from front edge of the seat pan to the back edge of the seat pan) should be 42.5 cm. (17 in.) while the minimum seat depth (i.e., from the front edge of the seat pan to the backrest) should be 35.5 cm. (14 in.).

recommended for industrial or office chairs because of the varied conformation of the human buttocks and perineal region as well as the difficulty of changing position in a shaped seat (Croney, 1971; Damon, Stoudt, & McFarland, 1966). The seat pan may be slightly concave in the center to prevent sliding out of the seat by helping maintain the user in the middle of the seat (Ayoub, 1971; Kroemer, 1971). The exposed seat pan should not have any sharp edges. The seat front should be curved downward to eliminate pressure on the popliteal area (Murrell. 1969). The seat pan should be upholstered. On a hard seat suface, the trunk weight is transmitted through the small areas causing a high pressure point. The high pressure point results in reduced blood flow leading to numbness and pain. Contrarily, soft upholstery is not recommended since the softness makes it difficult to gain relief by adjusting the user's body. The seat pan upholstery should not only reduce pressure on the buttocks, but also permit changes of posture. Therefore the upholstery should be stiff and not give more than 1 inch (Darcus and Weddell, 1947). In addition, the upholstery should afford ventilation to reduce sweating (Branton, 1969; Grandjean, Hunting, Wotzka, & Scharer, 1973).

Seat pan slope

Most authors recommend that the seat pan should have a slight rearward slope of 3° to 7° (Grandjean et al., 1973; Keegan, 1953). A horizontal seat pan would cause the user to be ejected from the seat if he leans against the backrest. The user must counterbalance the forward thrust by maintaining muscular tension which leads to fatigue (Ayoub, 1971; Kroemer, 1971). A slight rearward slope is recommended which will cause the user's trunk to tilt towards the backrest, and at the same time prevent ejection of the user (Murrell, 1969). However, if the backrest is not used, the rear slope of the seat pan will tend to rotate the pelvis backward causing deformation of the spine (Ayoub, 1971; Kroemer, 1971). As stated previously, if the seat pan is slightly concave in the center, the concavity will help prevent sliding by maintaining the user in the middle of the seat. Adjustability of the slope above and below the horizontal axis is very desirable (Kroemer, 1971).

Seat pan height

Sitting comfort is at a maximum when the weight of the trunk is borne mainly by the ischial tuberosities (the boney protuberances) (Lay & Fisher, 1940). According to Floyd and Roberts (1958), the thighs are anatomically and physiologically unsuited for supporting the weight of the sitting body. The seat pan height should be determined principally by the desirability of avoiding undue pressure on the soft tissues of the posterior aspect of the thighs (Croney, 1971; Floyd & Roberts, 1958).

The height of the seat pan is the distance from the front of the seat pan to the floor or the foot rest pan. If the seat pan height is properly adjusted, the user's lower legs and thighs should be, at right angles with his feet flat on the floor or foot rest pan (Croney, 1971). The height of the seat pan should be slightly less than the distance from the floor to the underside of the user's thigh (i.e., the user's popliteal height) (Hooton, 1945; Morrison, 1965). According to Morgan et al. (1963) as a general rule, tall people can accommodate to a low seat more easily than short people can accommodate to a high seat. However, some authors suggest that seats which are too low are not desirable. Keegan (1953), for example, considers that the acute angle between trunk and thigh formed by the low seat pan height should be avoided. The acute angle causes an unfavorable position of the pelvis and spinal column, as well as producing pressure on the abdominal organs. Since the popliteal height among individuals and sexes vary, the seat pan height should be adjustable (Croney, 1971). A foot rest pan may be employed to accommodate the smallest users to the seat height (Burandt & Grandjean, 1963; Murrell, 1969).

Seat pan width

The width of the seat pan is the distance between the two side edges of the pan. The seat width must be sufficient to accommodate the largest users and to facilitate changes of posture (Darcus & Weddell, 1947; Croney, 1971). Therefore, the seat width only has a minimum, not a maximum dimension. The seat pan width should be large enough to accommodate the largest user's bitrochantric width plus 25 percent of the width for shifting of position (Ayoub, 1971). The minimum width is based on the need for support of the ischial tuberosities of the largest users (Floyd & Roberts, 1958).

Seat pan depth

The seat pan depth corresponds to the distance from the front edge of the seat pan to the intersection of the rear edge with the backrest or backrest plane (Grandjean, 1973). Seat pans that are too deep may cause excessive pressures on the back of the knee (Murrell 1969). Additionally, if the seat pan is too deep, the user may shift his buttock forwards and will not be able to lean against the backrest. The seat pan depth should be slightly less than the smallest user's buttock-to-popliteal length (Damon, et. al., 1966). An adjustable backrest swivel allows users of different buttock-to-popliteal length to sit in the same seat pan (Ayoub, 1971).

BACKREST DESIGN

A well designed backrest is a very important component of the chair, even if the backrest is used only occasionally. The size of the backrest depends on the type of tasks which the user is involved at the time he is sitting (Ayoub, 1971). For example, if a seat is to be used in operations where freedom of the shoulders and arms are necessary, then only the lower part of the back should contact the backrest. The proposed backrest shape and dimensions as found in the literature are contained in table B-3. Table B-4 presents a summary of the discussion and recommendations of the shape and dimensions of the backrest.

Backrest shape

The shape of the backrest depends on the necessity of the user to move his arms and shoulders. If mobility of shoulders and arms is necessary, a small kidney-shaped backrest should be provided. If the seat is to be used in operations where freedom of the shoulders and arms are not necessary, the backrest can be larger in size. In both cases, the backrest should be slightly concave toward the sitting person in the top view and in the side view slightly convex (Kroemer & Robinnette, 1968). The edges of the backrest should prevent painful pressure and facilitate changes of posture. The backrest should not have any sharp edges, but instead the edges should be carefully rounded and well padded (Grandjean et al., 1973).

Table B-3. Proposed Shape and Dimensions of the Seat Pan

Dimension	Reference	Recommendation	Remarks
Backrest surface shape	Ayoub, M.M. (1971)		The shape of the backrest surface should be slightly convex in profile.
	Croney, J. (1971)		The backrest should allow the back freedom to be "arched" occasionally and improve the lumbar curve.
	Floyd, W.F., & Roberts, D.F. (1958)		The backrest should be saddle-shape as recommended by Akerblom. The shape should be anteriorly convex with a sagittal profile.
	Grandjean, E., Hunting, W., Wotzka, G., & Scharer, R. (1973)		The backrest should be gently rounded for lumbo-sacral support
	Karvonen, M.J., Koskela, A., & Noro, L. (1962)		The chair should give good support to the lumbar spine. A lumbar support which is slightly convex in the vertical plane and concave in the horizontal one fits the shape of the backrest.
	Kocker, A.L. & Frey, A. (1932)		The backrest should be convex for lumbar support.
	Kroemer, K.H.F. (1971); Kroemer, K.H.E., & Robinette, J.C. (1968)		The backrest should be slightly concave toward the sitting person and slightly convex in the side view. The edges of the backrest should be rounded. The backrest should be stiffly upholstered.
	McFarland, R.A., Damon, A., Stoudt, H.W., Moseley, A.L., Dunlap J.W., & Hall, W.A. (1953)		The backrest should slope backwards in order to carry an increasing amount of the body weight as the slope itself increases. A slightly S-shaped backrest may be preferable to a flat or concave one. With an S-shaped backrest, the user can adapt himself to it by shifting his buttocks forwards or backwards.

Table B-3. Continued

Dimension	Reference	Recommendation	Remarks
Space between seat pan and backrest	Akerblom, B. (1954)	20 cm.	Lumbar support should begin at the top of the sacrum.
	Ayoub, M.M. (1971)	3-6 in.	The space between the backrest and seat pan allows the pelvis to be moved back permitting support of the lumbar spine by the backrest.
	Burandt, U., & Grandjean, E. (1963)	14-24 cm.	
	Croney, J. (1971)	6-7.5 in. (males) 5-7.5 in. (females)	The lumbar region should be raised clear of the sacral region. The height should be adjustable.
	Darcus, H.D., & Weddell, A.G.M. (1947); Weddell, A.G.M., & Darcus, H.D. (1947)	7.5-8 in.	Backrest should be positioned 0.5 inches behind the back of the seat to allow for a good sitting position of the operator.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	7-8 in. .4 in. (minimum)	These dimensions are based on backrests which only support the lumbar region.
	Floyd, W.F., & Roberts, D.F. (1958)	8 in.	The open space allows the bottom of the edge of the backrest to clear the sacral region.
	Grandjean, E., Hunting, W., Wotzka, G., & Scharer, R. (1973)	17 cm.	
	Karvonen, M.J., Koskela, A., & Noro, L. (1962)	10-15 cm.	Distance between the lower edge of the backrest and the seat for school children.
	Keegan, J.J. (1953, 1962)	4.5 in.	The open space is for the posteriorly projecting sacrum and buttocks. The open space permits contact with the primary lower back support.
	Kroemer, K.H.E. (1971); Kroemer, K.H.E., & Robinette, J.C. (1968)	8-15 cm.	The backrest should either have an opening or recede just above the seat surface so that the sacrum can be pushed back and lumbar contact made.

Table B-3. Continued

Dimension	Reference	Recommendation	Remarks
	Kubokawa, C., & Woodson, W. (1969)	6 in.	The space between the backrest and the seat pan should be adjustable in 2 inch decrements/increments.
	Morgan, C.T., Cook, J.S. Chapanis, A., & Lund, M.W. (1963)	7-8 in.	For small-of-the-back support.
	Morrison, J.F., (1965)	20 cm.	
	Murrell, K.H. (1969)	8 in. (minimum)	The open space allows the buttock to protrude beyond the backrest.
	Oxford, H.W. (1969)	8 in.	Recommended for educational chairs.
	Woodson, W.E., & Conover D.W., (1964)	7-10 in. (adjustable) 5 in.	For secretarial chairs. For special operator chairs.
Backrest height	Ayoub, M.M. (1971)	7 in.	If the seat is to be used in operations where freedom of the shoulders and arms are necessary, a small backrest should be provided.
	Burandt, U., & Grandjean E. (1963)	20 cm.	
	Croney, J. (1971)	4-6 in. 8 in. 20-25 in. 35 in.	Lumbar support height for males. Lumbar support height for females. For shoulder support. For back or head support.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	5-6 in. 18-20 in. 34 in.	For lumbar support For shoulder support For head support
	Darcus, H.D., & Weddell, A.G.M. (1947); Weddell, A.G.M., & Darcus, H.D. (1947)	5 in.	The backrest should fit accurately into the lumbar hollow.

Table B-3. Continued

Dimension	Reference	Recommendation	Remarks
	Floyd, W.F., & Roberts, D.F. (1958)	13 in.	The upper edge of the backrest should clear the shoulder blades. The support is most effective when provided within the range of the 2nd to 5th lumbar vertebrae.
	Grandjean, E., Hunting, W., Wotzka, G., & Scharer, R. (1973)	27 cm.	
	Hooton, E.A. (1945)	28 in.	Measured from the seat to the top of the backrest. Based on the region of the 1st and 2nd cervical vertebrae (sitting).
	Karvonen, M.J., Koskela, A., & Noro, L. (1962)		The backrest should not reach up to the shoulder blades, if the movement of the upper limbs are not to be restricted.
	Keegan, E.F. (1953, 1962)	9 in.	The back support should be placed next to the lower lumbar spine.
	Kroemer, K.H.E. (1971); Kroemer, K.H.E., & Robinette, J.C. (1968)	18 cm. 50-60 cm.	For lumbar support only. For full-sized backrest. The backrest may raise up to shoulder height.
	Kubokawa, C., & Woodson, W. (1969)	15 in.	
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)	18-20 in. 34 in. 5-6 in.	For shoulder support. For head support. For small-of-the-back support, with the bottom edge 7-8 in. above the seat pan.
	Morrison, J.F. (1965)	13 cm.	
	Murrell, K.H. (1969)	4-8 in.	
	Ridder, A.C. (1959)		The backrest height for chairs designed for writing (alert positions) should be 17.5 in. in a diagonal line from the seat to top of the chair back. The backrest height for chairs designed for talking should be 18 in. from the seat to the shoulder line, or 22 in. from the seat to center of the neck.

Table B-3. Continued

Dimension	Reference	Recommendation	Remarks
	SAE Standard	23-25 in.	Recommended for seats for flight crewmen.
	Van Cott, H.P., & Kinkade, R.G. (1972)	6 in.	Minimum length recommended.
	Woodson, W.E., & Conover, D.W. (1964)	6-8 in. 12 in.	For secretarial chairs. For special operator chairs.
Backrest width	Ayoub, M.M. (1971)	13 in.	If mobility of shoulders and arms are necessary.
	Croney, J. (1971)	20 in. minimum 12-14 in.	For the backrest width at shoulder level or above for leisure and lounge seating. Based on the shoulder widths of the largest users. The backrest width at 14 in. high should be 15 to 16 in. For working positions to give a free space for the user's elbows.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	20 in. 12-13 in.	If shoulders are to be supported. For lumbar support.
	Darcus, H.D., & Weddell, A.G.M. (1947); Weddell, A.G.M., & Darcus, H.D. (1947)	15 in.	
	Hooton, E.A. (1945)	22 in. but can use 19 in.	Based on the shoulder breadth.
	Kroemer, K.H.E. (1971); Kroemer, K.H.E., & Robinette, J C. (1968)	18 cm. 38 cm.	For lumbar support only. For full-sized backrest.
	Kubokawa, C., & Woodson, W. (1969)	16 in. 13 in.	 To clear the elbows.

Table B-3. Continued

Dimension	Reference	Recommendation	Remarks
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)	20 in. 12-13 in.	For support across the shoulders. For small-of-the-back support.
	Murrell, K.H. (1969)	13 in. (maximum)	The small backrest width should avoid hitting the backrest with the elbows when the hands are drawn towards the hips.
	Ridder, C.A. (1959)		The backrest width should be 13.5 in. across the top of the backrest and 10.0 in across the bottom.
	Van Cott, H.P., & Kinkade, R.G. (1972)	12-14 in.	
	Woodson, W.E., & Conover, D.W. (1964)	12-14 in 15 in.	For secretarial chairs. For special operator chairs.
	Wotzka, G. Grandjean, E., Burandt, U., Kretzschmar, H., & Leonard, T. (1969)	500 mm.	For student seats.
Curvature of backrest	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	Radius of 7.3 in.	The lumbar support lateral curvature should not be deeper than that of a circle 7.3 inches in radius. The backrest should be convex rather than concave.
	Darcus, H.D., & Weddell, A.G.M. (1947); Darcus, H.D., & Weddell, A.G.M. (1947)	Radius of 7.3 in.	The curve of the backrest should correspond to the natural curvature of the lumbar region.
	Floyd, W.F., & Roberts, D.F. (1972)	12 in. 16-18 in.	Radius must not be less than this minimum. Radius that is usually preferred.

Table B-3. Continued

Dimension	Reference	Recommendation	Remarks
	Kubokawa, C., & Woodson, W. (1969)	4 in.	Maximum curve
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)	Radius 7.3 in. 16-18 in.	For small-of-the-back support. For backrests at shoulder or head height, the radius should never be less than 12 in., but such backrests need not be curved at all.
	Nissley, H.R. (1951)	9 in.	The backrest should have a small radius.
Backrest angle	Akerblom, B. (1954)	115°	For ordinary chairs.
	Burandt, U., & Grandjean, E. (1963)	100°	
	Croney, J. (1971)		An angled backrest assists the force of gravity to settle the user's body into the chair.
		135°	For reclining in comfort.
		110°-120°	For conference seating, relaxed traveling position.
		95°-110°	For alert or attention sitting.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	115°	
	Floyd, W.F., & Roberts, D.F. (1958)	100°-110°	
	Grandjean, E., Boni, A., & Kretzchmar, H. (1969)	101°-104° (reading) 105°-108° (rest)	Recommended for easy chairs.
	Jones, J.C. (1969)	108°	
	Karvonen, M.J., Koskela, A., & Noro, L. (1962)	90°-100°	The angle recommended for school chairs.

Table B-3. Continued

Dimension	Reference	Recommendation	Remarks
	Keegan, E.E. (1953, 1962)	105°	This is the minimum angle to help preserve the lumbar curve.
	Kennedy, K.W., & Bates, Jr., C. (1965)	103°	Back of the seat should slope away from the front of the console at about 13° from the vertical.
	Kroemer, K.H.E. (1971); Kroemer, K.H.E., & Robinette, J.C. (1968)	$\pm$15° 105°-120°	For lumbar support only, tiltable $\pm$15° against vertical about a horizontal axis. For full-sized backrests.
	Kubokawa, C., & Woodson, W. (1969)	95°-115°	
	Le Carpentier, E.F. (1969)	110.0° (both) 113.0° (males) 105.0° (females)	Recommended for easy chairs.
	McFarland, R.A., Damon, A., Stoudt, H.W., Moseley, A.L., Dunlap, J.W., & Hall, W.A. (1953)	115°-120°	For vehicular design.
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)	103°-115°	For most seated positions.
	Ridder, C.A. (1959)		For chairs designed for writing (alert position), the backrest angle should be 15° back from the true vertical. For chairs designed for talking, there should be a 3.8 in. backward slant or 25° back angle from the true vertical, between the points which rest 4.0 to 13.0 in. above the chair seat.
	Van Cott, H.P., & Kinkade, R.G. (1972)	95°-105°	
	Woodson, W.E., & Conover, D.W. (1964)	90°-110° 97°-109°	For secretarial chairs. For special operator chairs.

Table B-3. Concluded

Dimension	Reference	Recommendation	Remarks
	Wotzka, G., Grandjean, E., Burandt, U., Kretzschmar, H., & Leonard, T. (1969)	108°	

Table B-4. Summary of the Discussion and Recommendations for the Shape and Dimensions of the Backrest.

Dimension	Discussion	Remarks	Previous Recommendations
Backrest shape	The backrest shape and size are dependent upon whether mobility of the shoulders and arms is necessary. If mobility is necessary, a small backrest should be employed; if mobility is not necessary a larger backrest can be used. The backrest should also facilitate changes in positions.	The backrest should be slightly concave toward the sitting person in the top view and slightly convex in the side view. The backrest should support the lumbar spine.	Viewed from the top, the backrest should be slightly concave toward the sitting person and viewed from the side slightly convex. The size of the backrest should be approximately 32 x 18 cm. (13 x 7 in.). The full sized backrest should be approximately 38 cm. (15 in.) wide with the height dependent on whether the backrest is for shoulder rest or for head rest. The edges of the backrest, especially at the top and bottom, should be carefully rounded and well padded.
Space between seat pan and backrest	The space between the backrest and seat pan is for the user's sacrum, permitting the lumbar spine to be supported by the backrest.	The opening should be higher than the largest users (e.g., 95th percentile) L-5 vertebral sitting height. The opening should be adjustable for different users' L-5 vertebral sitting height.	If not adjustable, the backrest lower edge should be approximately 10 cm. (4 in.) above the seat pan. If adjustable, the backrest lower edge should be 8 to 15 cm. (3 to 8 in.) above the seat pan.

Table B-4. Continued

Summary of the Discussion and Recommendations for the Shape and Dimensions of the Backrest

Dimension	Discussion	Remarks	Previous Recommendations
Backrest height	The backrest height is dependent on whether mobility of the shoulders and arms is necessary. If mobility is necessary, a small kidney-shaped backrest should be used; if mobility is not necessary a full-sized backrest can be provided.	If mobility of the shoulders and arms is necessary, the backrest should fit accurately into the lumbar hollow (above the sacrum), below the T-12 vertebra, and should not impinge on the iliac crests, thereby giving support to the lumbar spine. The height of the backrest should be set at the smallest user's (e.g. 5th percentile) L-1 and L-5 vertebral distance with a width set at the smallest (e.g. 5th percentile) user's distance between illial crests. If mobility of the shoulders and arms is not necessary, the backrest can rise above the T-12 vertebra, but the backrest must still protrude anteriorly at the sacral junction to support the lumbar region.	If mobility of the shoulders and arms is required, the lower edge of the backrest should be approximately 18 cm. (7 in.) in height. The upper edge of the backrest should be 30 - 35 cm. (12 - 14 in.) above the seat pan. If mobility of the shoulders and arms is not necessary, the backrest height can be approximately 50 - 60 cm.(20 - 24 in.) over the seat pan for shoulder support and 89 cm. (35 in.) over the seat pan for back and head support.

Table B-4. Concluded

Summary of the Discussion and Recommendations for the Shape and Dimensions of the Backrest

Dimension	Discussion	Remarks	Previous Recommendations
Backrest width	The backrest width depends on whether mobility of the shoulders and arms is necessary.	If task mobility or turning is necessary, the width must be less than the smallest users' (e.g., 5th percentile) bi-illiac crest width. If mobility is not necessary, the width should support the largest users' shoulders.	For lumbar support only, the backrest width should be approximately 32 cm. (13 in.). If mobility is not necessary, the backrest should be at least 38 cm. (15 in.).
Curvature of backrest	For lumbar support, the curvature of the backrest should correspond to the natural curvature of the lumbar region.	The average curve is an arc of a circle of a radius of 7.3 in. Since the human lumbar curve is convex forward, the backrest should be designed with a convex rather than a concave lumbar support.	The backrest should be designed with a convex lumbar support.
Backrest swivel and angle	The backrest swivel allows a better fit between the curvature of the spine and the backrest. An angled backrest assists the force of gravity to settle the user's body into the chair.	The backrest should swivel $\pm 15^{\circ}$ against the vertical about a horizontal axis. The backrest should not swivel so easily that the support is wobbly.	The lumbar-support backrest swivel should be $\pm 15^{\circ}$ against the vertical axis about a horizontal axis. For full-sized backrests, the angle should be approximately 105°-120°.

Space between seat pan and backrest

The space between the seat pan and backrest allows the pelvis to be moved back permitting support of the lumbar spine by the backrest (Floyd & Roberts, 1958; Keegan, 1952). The lumbar support should begin at the top of the sacrum (Äkerblom, 1954; Croney, 1971). Hence the opening should be adjustable to accommodate the largest user's L-5 vertebral sitting height. If there is no space between the seat pan and the backrest, the backrest should be recessed to provide space for the protrusion of the buttocks (Damon et al., 1966).

Backrest height

The height of the backrest is dependent on the user's necessity of moving his arms and shoulders. The support is most effective when provided within the range of the 2nd to 5th lumbar vertebrae (Floyd & Roberts, 1958). If mobility of the shoulders and arms is necessary, the height should be set at the smallest user's medial L-1 and L-5 vertebral height. The backrest should fit accurately into the user's lumbar hollow (i.e., above the sacrum and below the T-12 vertebra). If mobility of the shoulders and arms is not necessary, the backrest can rise above the T-12 vertebra (Ayoub, 1971; Kroemer, 1971).

Backrest width

The width of the backrest is dependent on the necessity of mobility of the user's shoulders and arms. For mobility, the width must be less than the smallest user's bi-illiac crest width. The backrest should not hinder free movement of the elbows (Murrell, 1969; Croney, 1971). If mobility of shoulders and arms is not necessary, the width of the backrest should provide full support across the shoulders. Hence in this case, the width of the backrest is based on the largest user's shoulder breadth (Hooton, 1945).

Curvature of the backrest

For lumbar support only, the lateral curvature of the backrest should not be deeper than that of a circle 7.3 inches in radius (Weddell & Darcus, 1947). On the other hand, since the human lumbar curve is convex forward, the backrest should be designed with a convex rather than a concave lumbar support (Damon et al., 1966). For backrests at shoulder or head height, curvatures should have radii of from 16 to 18 inches, but never less than 12 inches (Floyd & Roberts, 1958).

Backrest swivel and angle

The backrest should swivel to allow a better fit between the curvature of the spine and the backrest. The backrest swivel can also be used as a type of seat pan depth adjustability. The backrest swivel helps accommodate users of different Buttock-to-Popliteal lengths to the seat pan depth (Ayoub, 1971). A slightly tilted backrest helps the user to settle comfortably in a chair and prevents a gradual slide forward of the body. According to Croney (1971), without the tilt of a backrest the lumbar curve is unnaturally flattened and strain is placed on the intervertebral lumbar discs and ligaments. The backrest angle depends on the type of activity in which the user is involved.

ARM REST DESIGN

Table B-5 compiles the proposed dimensions of the arm rests as contained in the literature. A summary of the discussion and recommendations for

Table B-5. Proposed Dimensions of the Arm Rest

Dimension	Reference	Recommendation	Remarks
Arm rests heights	Croney, J. (1971)	8-8.5 in. 7.5-10 in.	For non-adjustable arm rest height. For adjustable arm rest height.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	8-10 in.	Based on the elbow rest height (sitting).
	Hooton, E.A. (1945)	8.5 in.	Based on elbow height.
	Kennedy, K.W., & Bates, Jr., C. (1965)	9 in.	
	Kubokawa, C., & Woodson, W. (1969)	8.5 in	Adjustment to arm rest height should be in 2.5 inch decrements/increments.
	Le Carpentier, E.F. (1969)	6.5 in.	Recommended for easy chairs.
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)	8-10 in.	Whenever possible, the operator's arm should be supported so that it lies in the same plane as the work surface. This arrangement will support the arm without forcing the operator to raise or depress his shoulder.
	Morrison, J.F. (1965)	27 cm. American population	Height of the arm rests should be related to the 95th percentile value of measurements taken from the seat pad to the point of the elbow.
	Murrell, K.H. (1969)	8.5-9.0 in.	
	Ridder, A.C. (1959)		For chairs designed for writing (alert positions), the best arm rest height is 8 in. above the seat. For chairs designed for talking, the best arm rest height is 7.7 in. above the seat.

Table B-5. Continued

Dimension	Reference	Recommendation	Remarks
	SAE Standard	8-12.5 in.	Recommended for seats for flight crewmen.
	Van Cott, H.P., & Kinkade, R.G. (1972)	7-9 in.	
	Woodson, W.E., & Conover, D.W. (1964)	9 in.	
Arm rests width	Kubokawa, C., & Woodson, W. (1969)	2 in.	
	SAE Standard	3 in.	Recommended for seats for flight crewmen.
	Woodson, W.E., & Conover, D.W. (1964)	2 in.	
Arm rest length	Keegan, E.E. (1953, 1962)		Arm rests should support the soft muscle part of the forearm, not beneath the elbows. There should be an open or lower space directly beneath the elbow.
	Kennedy, K.W., & Bates, Jr., C. (1965)	8.25 in.	The arm rest should not interfere with the use of the writing leaf. The arm rest should not extend more than 8.25 in. forward from the seat reference point. (SRP).
	Kubokawa, C., & Woodson, W. (1969)	9-12 in.	The arm rest length should be in 2 inch increments/decrements.
	Murrell, K.H. (1969)	10-12 in.	Measured from the back of the seat.
	SAE Standard	11 in.	Recommended for seats for flight crewmen.
	Van Cott, H.P., & Kinkade, R.G. (1972)	9-12 in.	
	Woodson, W.E., & Conover, D.W. (1964)	10 in.	

Table B-5. Concluded

Dimension	Reference	Recommendation	Remarks
Arm rests separation	Ayoub, M.M. (1971)		The arm rests should not interfere with getting into and out of the chair. At times, one arm rest on one side usually suffices.
	Croney, J. (1971)	19 in.	
	Kubokawa, C., & Woodson, W. (1969)	18-19 in.	
	Murrell, K.H. (1969)	19 in.	
	Ridder, C.A. (1959)		For chairs designed for writing (alert positions), the single best arm rest separation width is 20 in. between the inner edges. For chairs designed for talking, the single best arm rest separation is 21 in. between the inner edges.
	SAE Standard	17.5 in.	Recommended for seats for flight crewmen.
	Van Cott, H.P., & Kinkade, R.C. (1972)	19 in.	

arm rests is presented in table B-6. Arm rests may be used to decrease the load on the spinal column by propping the arms. The arm rests are also helpful in changing position and as an aid in getting up from the chair (Croney, 1971). Often where required, one arm rest on one side of the chair will suffice with the advantage that one arm rest will not interfere with getting into and out of the chair (Ayoub, 1971). In addition, arm rests can be helpful in tasks which require delicate assembly or adjusting tasks (Croney, 1971). In these type of tasks, the operator's elbows or lower arms can be supported by individually adjusted arm rests to stabilize the hands (Kroemer, 1971). Contrarily, arm rests can be hindering to tasks that require free mobility of the trunks, shoulders, and arms (Damon et al., 1966). The arm rests surface should not be too soft or to smooth. Arm rests should be individually adjusted since arm rests that are too high tend to lever the user out of the chair and also bring unnatural pressure on the shoulder joints (Croney, 1971). At times, the table/desk can act as the arm rest by having the user rest his forearms and hands on top of the table/desk. The table/desk can also have an arm rest support affixed to it which may be raised or lowered out of the way when not in use (Ayoub, 1971).

FOOT REST DESIGN

Foot rests help to compensate for a seat pan that is too high for a user (Croney, 1971). The surface of the foot rest pan should be as large as the floor area upon which the user could possibly place his feet. Very small foot rest areas should be avoided since changes in foot and leg positions are hindered (Roebuck, Kroemer, & Thomson, 1975).

Table B-6. Summary of the Discussion and Recommendations for Arm Rests

Dimension	Discussion	Remarks	Previous Recommendations
Arm rests	Arm rests can decrease the load on the spinal column, as well as help in changing positions or as an aid in getting into and out of the seat. Arm rests can hinder tasks which require mobility of the trunk, shoulders, and arms.	Arm rests can not be too long, otherwise the user can not move as close to the table/desk as the prescribed correct position. The arm rest should not interfere with use of the table/desk. Adjustment can be made either by inward (outward) and fore-aft positioning of the upper arm, to shorten the vertical distance between the shoulder and the elbow, or by elevating the shoulders. Therefore, the arm rest should be 1 or 2 inches above the mean anthropometric measurement for fitting most users. At times, the table/desk can act as the arm rest, the user can rest his forearms/hands on the table/desk. The table/desk top can also have an arm rest support affixed to it instead of the chair.	In critical situations, an adjustable arm rest should be utilized. The minimum and maximum range for arm rest heights should be approximately 19 to 25 cm. (7.5 to 10 in.). A useful distance between arm rests is 48 cm. (19in.).

Horizontal rods or foot rings attached to the table or seat are undesirable because they generally require continuous muscle tension to keep the foot on the bar and the small rods/rings do not permit leg and foot posture changes (Murrell, 1969). The surface of the foot rest pan may be inclined up to 30° in front of the user, providing support for the feet so that even with the legs stretched out, the front edge of the seat does not cut into the underside of the thighs or popliteal (Croney, 1971). The foot rest pan should also be concave to accommodate the normal movement of the foot (Ayoub, 1971). Table B-7 includes the proposed shape and dimensions of foot rests as found in the literature. An integration of the discussion and recommendations of foot rests is presented in table B-8.

OTHER SEAT DESIGN FEATURES

In addition to the design features discussed above, other features are also important in seat design. Horizontal struts or other obstructions should not be placed between the front legs of the chair or underneath the front part of the chair (Floyd & Roberts, 1958). According to Keegan (1962), the space between the floor and the front of the seat should be open to permit the user to place his feet underneath the seat. The open space beneath the front part of the seat permits changes in position, as well as facilitates rising from the seat. In addition, space for the free movement of the legs under the seat assists in maintaining the lumbar curve during sitting since the backward movement of the legs relaxes the posterior muscles of the thigh and allows the pelvis and sacral spine to rotate and maintain a normal relationship with the lumbar spine (Croney, 1971).

Table B-7. Proposed Shape and Dimensions of the Foot Rests

Dimension	Reference	Recommendation	Remarks
Foot rests	Ayoub, M.M. (1971)		The shape of the foot rest should be concave to accommodate the normal movement of the feet.
	Burandt, U., & Grandjean, E. (1963)		The foot rest height should be up to 10 cm. for 78 cm. office desks or 5 cm. for 72 cm. office desks.
	Croney, J. (1971)		The overall foot rest surface needs to be large enough to rest the whole foot. The angle between the lower leg and the base of the foot should be normal or about 90° to 100°. If the foot rest surface is greater than 15° from the horizontal, a heel stop should be used.
	Darcus, H.D., & Weddell, A.G.M., (1947); Weddell, A.G.M., & Darcus, H.D. (1947)	15 in. wide 14 in. long	The foot rest should be wide and large enough to accommodate the largest foot.
	Ely, J.H., Thomson, R.M. & Orlansky, J. (1956)		The foot rest should allow each foot to be normal (90°-100°) to the lower leg. If the foot rest is at an angle of more than 20° from the horizontal, a heel support (between 1.0 and 1.5 in. thick to minimize interference with leg movements) should be provided to prevent the foot from sliding downward.
	Kroemer, K.H.E. (1971); Kroemer, K.H.E., & Robinnette, J.C. (1968)	15 in. wide (minimum)	The foot rest must be a large surface, if not relaxing changes in foot and leg position are hindered. Instead of being flat, the surface of the foot rest may be inclined up to 30° in front of the sitting person.

Table 3-7. Concluded

Dimension	Reference	Recommendation	Remarks
	Kubokawa, C., & Woodson, W. (1969)	10 in. long 6 in. wide	The distance of the foot rest from the center of the chair should be 7 in.
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)		The foot rest should allow each foot to be about normal (90°-100°) to the lower leg. If the foot rest is at an angle of more than 20° from the horizontal, a heel rest should be provided to prevent the foot from sliding downward. This heel support should be between 1 and 1.5 in. thick to minimize interference with leg movements.
	Murrell, K.H. (1969)		The foot rest should be a flat surface rather than a bar which will cause fatigue by forcing the operator to keep his feet in a fixed position.
	Nissley, H.R. (1951)		Foot rests should be provided and should be easily adjustable in height.

Table B-8. Summary of the Discussion and Recommendations for Foot Rests

Dimension	Discussion	Remarks
Foot rests	Foot rests are advantageous when the seat pan is too high for a user. Very small foot rest areas, as well as horizontal rods or foot rings attached to the table or seat should be avoided, since they hinder leg and posture changes.	The surface of the foot rest pan may be inclined up to 30° in front of the user, providing support for the feet so that even with the legs stretched out, the front edge of the seat does not cut into the underside of the thighs. If the foot rest surface is greater than 15° from the horizontal a heel stop should be used. The angle between the base of the foot and the lower leg should be normal or about 90° to 100°. The foot rest should be concave to accomodate the normal movement of the foot.

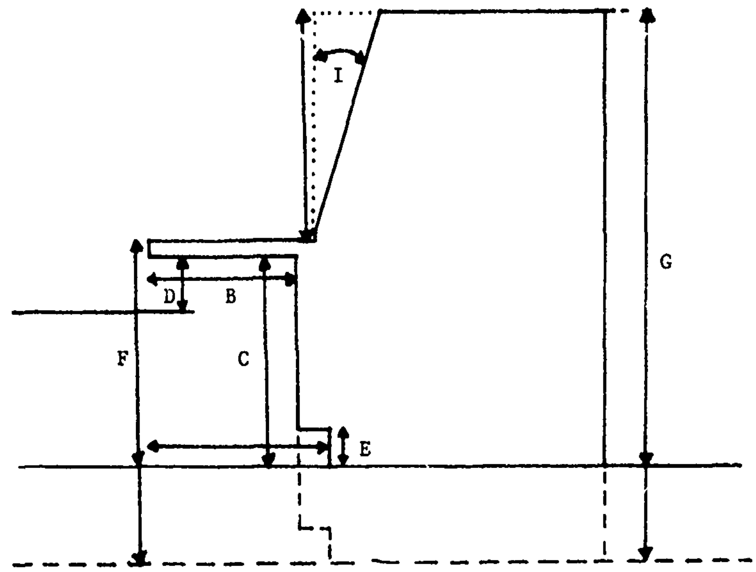
According to Ayoub (1971), a seat rotating about a pivot is often desirable when the operator has to turn to perform his task such as when L- or U-shaped console/workplace are employed. The swivel seat allows the operator to rotate from one area of the console/workplace to another with ease. A desirable feature on the swivel seat is a lock by which the seat can swivel or made stationary.

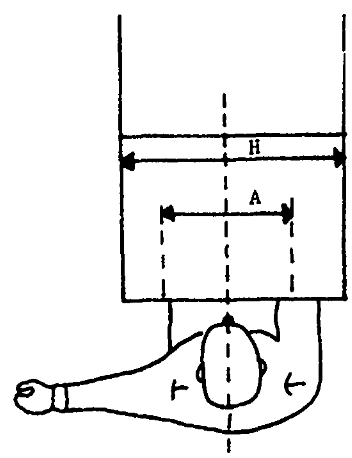
CONSOLE/WORKPLACE LEG ROOM DESIGN

The main design features of a console/workplace for the seated operator is presented in figure B-2. To properly accommodate the seated operator, the console/workplace must provide adequate leg room. If the leg room is not adequate, the console/workplace should be designed for the standing operator. Therefore, minimum values are needed for each leg room dimension of the console/workplace design. Table B-9 presents the proposed leg room dimensions for the console/workplace design as recommended in the literature. A summary of the discussion and recommendations of the leg room dimensions are included in table B-10.

Leg room width clearance

The leg room width clearance is the distance or breadth for accommodation of the user's legs, especially the knees, under the work surface. The minimum leg room should permit some natural separation between the inner thighs of the largest users (Roebuck, et al., 1975). Damon et al. (1966) state that the knees can be comfortable considerably closer together than the normal resting position, if the knees are supported laterally. A wider leg room breadth is necessary, if the task necessitates freedom





A. Leg room width clearance
B. Leg room depth clearance
C. Leg room height clearance
D. Thigh clearance
E. Foot clearance
F. Height of the work surface
G. Maximum height of the console
H. Maximum console breadth
I. Optimum panel angle

Figure B-2. Main Design Features of a Console/Workplace for the Seated Operator

Table B-9. Proposed Dimensions Concerning Leg Room for a Console/Workplace for the Seated Operator

Dimension	Reference	Recommendation	Remarks
Leg room width	Ayoub, M.M. (1971, 1973)	20 in. (minimum)	
	Kroemer, K.H.E. (1971)	40 cm. (minimum) 65 cm. (desirable)	If the minimum open leg room width cannot be met, the workplace must be designed for the standing operator.
	Kubokawa, C., & Woodson, W. (1969)	20 in. (minimum)	
Leg room (knees) depth clearance	Ayoub, M.M. (1971, 1973)	12 in. (minimum)	Measured from the beginning of the desk to the front of the knees at knee level.
		25 in. (minimum)	Measured from the back of the seat to the front of the knees.
	Croney, J. (1971)	46 in.	Measured from the seat back to the front of the knees at knee level. Based on buttock-knee length.
	Floyd, W.F., & Roberts, D.F. (1958)	18 in.	Increase the depth to 24 in. to accommodate the legs and feet when stretched forward.
	Kennedy, K.W., & Bates, Jr., C. (1965)	18 in. (minimum)	For knee clearance.
	Kroemer, K.H.E. (1971)	30 cm. (minimum) 65 cm. (desirable)	If the minimum depth cannot be met, the workplace must be designed for the standing operator.
	Kubokawa, C. & Woodson, W. (1969)	26 in. (minimum) 16 in. (minimum)	Measured from the back of the seat. Measured from the beginning of the desk to the front of knees at knee level.
		24 in. (minimum)	Measured from the beginning of the desk to the front of the feet at foot level.

Table B-9. Continued

Dimension	Reference	Recommendation	Remarks
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)	26.5 in. (minimum)	For fore-and-aft clearance between the back rest and front of the knees.
	Morrison, J.F. (1965)	90 cm. (minimum)	From the back of the seat to the front of the toes.
	Van Cott, H.P., & Kinkade, R.G. (1972)	26 in. (minimum)	From back of the seat.
		16 in. (minimum)	Measured from the beginning of the desk to the front of the knees at knee level.
		24 in. (minimum)	Measured from the beginning of the desk to the front of the feet at foot level.
	Woodson, W.E., & Conover, D.E. (1964)	16 in. (minimum)	
Leg room height clearance	Ayoub, M.M. (1971, 1973)	24 in. (minimum)	The leg room height should be large enough to clear the operator's knees.
	Croney, J. (1971)	25.5 in. (minimum)	The minimum height should accommodate all knee heights including the value for the 95th percentile male.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	26 in.	Based ou the knee height (sitting). There should be a minimum of 8 in. from the seat to the underside of the desk. The 8 in. minimum is based on thigh clearance.
	Floyd, W.F., & Roberts, D.F. (1958)	25 in.	Measured from the ground. The table top thickness should not be more than 2 in.
	Kroemer, K.H.E. (1971)	60 cm. (minimum) 75 cm. (desirable)	If the minimum height cannot be met, the workplace must be designed for the standing operator.
	Kubokawa, C., & Woodson, W. (1966)	25 in. (minimum)	

Table B-9. Concluded

Dimension	Reference	Recommendation	Remarks
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)	24.5 in. (minimum)	Distance from the floor to the underside of the work surface.
	Van Cott, H.P., & Kindade, R.G. (1972)	25 in. (minimum)	
Thigh clearance	Akerblom, B. (1954)	30 cm.	Distance between the seat of the chair and the table top.
	Croney. J. (1971)	9 in.	Minimum thigh clearance.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	8 in.	Based on thigh clearance height. Advancing the foot lowers thigh clearance height but requires more space forward of the operator.
	Kennedy, K.W., & Bates, Jr., C. (1965)	6.5 in.	Minimum thigh clearance at midpoint of seat height adjustability.
	Morgan, C.T., Cook, J. S., Chapanis, A., & Lund, M.W. (1963)	12 in.	Vertical distance between the seat and the work surface.
	Morrison, J.F. (1965)	18 cm.	Space between the top of the seat and the edging underneath the table or desk.
	Woodson, W.E., & Conover, D.W. (1964)	7 in. (minimum)	
	Wotzka, G., Grandjean, E., Burandt, U., Kretzschmar, H., & Leonard, T. (1969)	280 mm.	For student seats and desks.

Table B-10.

Summary of the Discussion and Recommendations for the Dimensions Concerning Leg Room for the Console/Workplace for the Seated Operator

Dimension	Discussion	Remarks	Previous Recommendations
Leg room width clearance	The leg room width clearance must be large enough to accommodate the inner thighs of the largest users, as well as to permit freedom of lateral movement.	The minimum width of the open leg room is based on the user's population largest (e.g., 95th) percentile for hip breadth, sitting. A wider width will be needed if the task necessitates freedom of lateral movement and/or rotation of the femur.	The minimum leg room width should be approximately 50 cm. (20 in.). If the leg room width is less than the 40 cm. (15 in.), the work-place/console should be designed for the standing operator. If the task necessitates freedom of lateral movement and rotation of the femur, a width of at least 65 cm. (25 in.) is recommended.

Table B-10. Continued

Summary of the Discussion and Recommendations for the Dimensions Concerning Leg Room for the Console/Workplace for the Seated Operator.

Dimension	Discussion	Remarks	Previous Recommendations
Leg room (knees) depth clearance	The leg room (knee) depth clearance should be large enough to accommodate the largest user's knees, if the abdomen is to be in contact with the desk/bench front.	If a writing table/bench is used, the minimum depth should accommodate insertion of the knees of the largest user's (e.g., 95th percentile) abdomen-knee length in order that the abdomen may be in contact with the desk/bench front. This dimension is usually not included in anthropometric survey data.* To estimate this dimension, one may subtract mid-respiration chest depth (selected in preference to standing abdomen depth to partially compensate for an increase in abdomen depth in the sitting position) from buttock-knee length. If no writing table is provided, a cut-out may or may not be provided. If the cut-out is provided, the minimum depth for the knees should be based on the largest user's (e.g., 95th percentile) abdomen-knee length. *Note: British data (Bolton, 1973) give the sitting stomach depth dimension and are roughly comparable to the U.S. military populations.	The minimum knee depth clearance has been recommended as no less than 30 to 45 cm. (12 to 18 in.), the specific minimum is based on both type and frequency of reaches required by the operator. The knee depth clearance should actually be at least 65 cm. (25 in.). If the minimum requirement can not be met, then the workplace/console should be designed for the standing operator.

Table B-10. Continued
Summary of the Discussion and Recommendations for the Dimensions Concerning Leg Room for the Console/Workplace for the Seated Operator.

Dimension	Discussion	Remarks	Previous Recommendations
Leg room (foot) depth clearance	If the minimum leg room (knee) depth clearance can not be met, a cutout should be provided so that the user can insert his feet. The leg room (foot) depth clearance must be large enough to accommodate the feet of the largest users.	The minimum leg room (foot) depth is based on the user's population largest (e.g., 95-th) percentile foot depth as measured from the abdomen to the front of the feet.	The minimum foot room depth clearance should be approximately 65 cm. (25 in.) measured from the front edge of the desk/bench to objects located in front of the user's feet.
Leg room height clearance	The leg room height clearance is the space needed underneath the bench /desk to accommodate the largest users' knees when his lower leg is vertical.	The minimum knee height clearance is based on the user's population largest (e.g., 95th) percentile knee height, plus shoe heel height.	The minimum knee height clearance should be approximately 61 cm. (24 in.). If the minimum knee height can not be met, the work-place/console should be designed for the standing operator.
Foot room height clearance	If a cutout is provided for insertion of the user's feet, the minimum foot room height clearance must be high enough to accommodate the feet of the largest users.	The minimum foot room height is based on the user's population largest (e.g., 95th) percentile foot height plus the height of the shoe heel.	The foot room height should be approximately 10 cm. (4 in.).

Table B-10. Concluded

Summary of the Discussion and Recommendations for the Dimensions Concerning Leg Room for the Console/Workplace for the Seated Operator.

Dimension	Discussion	Remarks	Previous Recommendations
Thigh clearance	The thigh clearance must be large enough to accommodate the largest user' thighs when the seat height is at the middle of its adjustability.	The minimum thigh clearance is based on the user's population largest (e.g., 95th) percentile thigh height.	The minimum thigh clearance should be approximately 16.5 cm. (6.5 in.) when the seat height is at the middle of its adjustability.

of lateral movement and/or rotation of the femur.

Leg room depth clearance

The leg room depth clearance is the distance between the front edge of the work surface and objects located in front of the user's leg, especially the user's knees. The minimum leg room depth should accommodate the insertion of the knees of the largest users so that the user's abdomen may be in contact with the front edge of the work surface (Roebuck et al., 1975). If the minimum requirement can not be met, then the console/workplace should be designed for the standing operator. If the minimum leg room (knee) depth clearance requirement is met, there should be a cutout near the floor to accommodate the insertion of the user's lower foot. The depth and height of the lower foot clearance depends on the largest user's foot depth and foot height. According to Roebuck et al. (1975), a minimum leg room depth of 18 inches permits some torso slump, assures space in front of the knee, and allows 90° knee angle if there is relief at the bottom of the desk to permit foot forward extension. A more generous open leg room than the minimum permits forward movement of the lower leg and, consequently, permits long-term seating comfort.

Leg room height clearance

The leg room height clearance is the distance between the floor or foot rest pan and the underside of the work surface. The minimum leg room height clearance should accommodate the largest users' knee height, plus shoe heel height, when the user's lower leg is vertical. The leg room height clearance is dependent on the work surface height (Ayoub, 1971; Kroemer, 1971). As the work surface height is decreased, there is a corresponding decrease in the leg room height clearance. If the minimum leg room height can not be met, the console/workplace should be designed for the standing operator. Foot pedal operation may raise the foot and consequently the knee (Damon, et al., 1966). If foot controls are used by the operator, the leg room height clearance is the distance from the foot control to the underside of the work surface.

Thigh clearance

The thigh clearance is the distance between the seat pan and the underside of the work surface (Morrison, 1965). The clearance must be sufficient to allow clearance of the upper surface of the knee and the thigh when shoes are worn (Floyd & Roberts, 1958). The minimum thigh clearance should accommodate the thighs of the largest users when the seat pan height is at the middle of its adjustability. According to Damon et al. (1966), advancing the foot lowers the thigh clearance height but requires more space forward of the operator.

CONSOLE/WORKPLACE DESIGN

As opposed to the leg room clearances, other console dimensions are based on maximum values. For example, the placement of controls should be based on the reach of the smallest operators. Table B-11 includes the recommended dimensions of a console/workplace as found in the literature. A summary of the discussion and recommendations of the console dimensions are presented in table B-12.

Height of the work surface

The height of the work surface can not be fixed and be useful for all types of tasks (Ayoub, 1973). For fine work, the work piece should be

Table B-11.

Proposed Dimensions of the Main Design Features of a Console/Workplace for the Seated Operator.

Dimension	Reference	Recommendation	Remarks
Height of the work surface	Äkerblom, B. (1954)	68-70 cm.	For table height.
	Ayoub, M.M. (1971, 1973)	males 39.0-41.5 in. females 35.0-37.5 in.	For fine work, exacting visual tasks.
		males 35.0-37.0 in. females 32.5-34.5 in.	For precision work.
		males 29.0-31.0 in. females 27.5-29.5 in.	For writing or light assembly work.
		males 27.0-28.5 in. females 26.0-27.5 in.	For course or medium manual work.
	Burandt, U., & Grandjean, E. (1963)	78 cm.	The seat should be 28 ± 2 cm. from the top of the desk. Two foot rests should be provided: [illegible] cm. and 10 cm.
		70-74 cm.	The seat should be 28 ± 2 cm. from top of desk, one footrest (5 cm.) should be provided.
		65 cm.	For typing table height.
	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	29 in. 25-25.6 in.	For tables, desks, or workbenches. For typewriting desks.
	Floyd, W.F., & Roberts, D.F. (1958)	27.5 in.	Based on a seat height of 17 in.
	Keegan, J.J. (1953, 1962)	30 in.	For reading.
	Kroemer, K.H.E., & Robinette, J.C. (1968)		The surface of the desk should be about at elbow height.
	Kubokawa, C., & Woodson, W. (1969)	29 in. (minimum) 30 in. (best)	For a writing desk, based on a seat height of 18 in.

Table B-11. Continued

Dimension	Reference	Recommendation	Remarks
	Morrison, J.F. (1965)		It is more efficient when working on a work surface height which is 5 to 15 cm. below the elbow height.
	Van Cott, H.P., & Kinkade, R.G. (1972)	26-30 in.	For a writing desk.
	Woodson, W.E., & Conover, D.E. (1964)	29-30 in.	
Height of the console top	Kennedy, K.W., Bates, Jr., C. (1965)	62 in.	For a sit-stand console.
		47.5 to 58 in.	For a sit console with vision over the console top. This dimension must never be more than 29.5 in. greater than the seat height at the midpoint of the seat adjustability.
		51.5 to 62 in.	For a sit console without vision over the console top. This dimension must never be more than 33.5 in. greater than the seat height at the midpoint of the seat adjustability.
		62 in.	For a stand console with vision over the console top.
		72 in.	For a stand console without vision over the console top.
	Kubokawa, C., & Woodson, W. (1969)	47 in. (maximum) 54 in.	In order to see over the console top. In order not to see over the console top.
	Van Cott, H.P., & Kinkade, R.G. (1972)	47 in. (maximum) 54 in.	In order to see over the console top. In order not to see over the console top.
Console panel breadth	Kennedy, K.W., & Bates, Jr., C. (1965)	36 in. (maximum) 44 in. (maximum)	For consoles without vision over the console top. For consoles with vision over the console top.
Work surface width	Kubokawa, C., & Woodson, W. (1969)	18 in. (minimum) 40 in. (maximum)	
	Van Cott, H.P., & Kinkade, R.G. (1972)	18 in. (minimum) 40 in. (maximum)	For consoles.

Table B-11. Concluded

Dimension	Reference	Recommendation	Remarks
Work surface depth	Kubokawa, C. & Woodson, W. (1969)	4 in. (minimum) 8 in. (best) 12 in. (minimum) 16 in. (best) 26 in.	For only elbow rest. For a writing surface. For a desk work area.
	Van Cott, H.P., & Kinkade, R.G. (1972)	16-18 in.	
Lateral work clearance	Damon, A., Stoudt, H.W., & McFarland, R.A. (1966)	24 in. (minimum) 41 in.	For elbow. For lateral arm movement.
	Kubokawa, C., & Woodson, W. (1969)	23 in. 25 in. 40 in.	For shoulders. For elbows. Best overall.
Placement of controls	Croney, J. (1971)	In front, 21 in. (maximum) 19.5 in. On sides, 30 in. (maximum) 28 in. (maximum)	At shoulder height. At waist height. At shoulder height. At waist height.
	Ely, J.H., Thomson, R.M. & Orlansky, J. (1956)	28 in. (maximum)	For instruments whose displays are located close to their controls, viewing distance is limited by reach distance. Viewing distance to displays should never be less than 13 in., and preferably not less than 20 in.
	Kubokawa, C., & Woodson, W. (1969)	28 in. (maximum)	On the sides of the operator.
	Van Cott, H.P., & Kinkade, R.G. (1972)	28 in. (maximum)	Placement of controls should not exceed this dimension.

Table B-12.

Summary of the Discussion and Recommendations of the Main Design Features of a Console/Workplace for the Seated Operator

Dimension	Discussion	Remarks	Previous Recommendations
Height of work surface	The height of the work place can not be fixed and be optimal for all types of tasks. Consequently, the height of the workplace is a function of the type of work performed.	(1) For fine work (e.g., exacting visual tasks) the work should be located 10 inches from eye position and 6 inches above elbow height. For this type of task, sitting is mandatory (2) For precision work (e.g., mechanical assembly work) the work surface should be 2 inches above the elbow height. The worker can be either standing or sitting with supported elbow. (3) For writing or light assembly work, the work surface should be 4 inches below the elbow height. The worker can be either standing or sitting.	(1) For fine work, the height of the work surface should be approximately 99 to 105 cm. (39 to 41.5 in.) for males and 89 to 95 cm. (35 to 37.5 in.) for females. (2) For precision work, the height of the work surface for the seated operator should approximately 89 to 94 cm. (35 to 37 in.) for males and 83 to 88 cm. (32.5 to 34.5 in.) for females; for the standing operator approximately 109 to 119 cm. (43 to 47 in.) for males and 103 to 113 cm. (40.5 to 44.5 in.) for females. (3) For writing or light assembly work, the height of the work surface for the seated operator should be approximately 74 to 79 cm. (29 to 31 in.) for males and 70 to 75 cm. (27.5 to 29.5 in.) for females; for the standing operator approximately 99 to 109 cm. (39 to 43 in.) for males and 88 to 98 cm. (34.5 to 38.5 in.) for females.

Table B-12. Continued

Summary of the Discussion and Recommendations of the Main Design Features of a Console/Workplace for the Seated Operator

Dimension	Discussion	Remarks	Previous Recommendations
Height of work surface		(4) For course or medium manual work (e.g., packaging), the work surface should be 8 inches below the elbow height. The worker can be either standing or sitting.	(4) For course or manual work the height of work surface for the seated operator should be approximately 69 to 72 cm. (27 to 28.5 in.) for males and 66 to 70 cm. (26 to 27.5 in.) for females; for the standing operator approximately 90 to 100 cm. (35.5 to 39.5 in.) for males and 79 to 94 cm. (31 to 37 in.) for females.

Table B-12. Continued

Summary of the Discussion and Recommendations of the Main Design Features of a Console/Workplace for the Seated Operator

Dimension	Discussion	Remarks	Previous Recommendation
Maximum height of the console without vision over the top	The maximum height of the console depends on whether the user is "sitting only", "standing only", or both "standing and sitting". The maximum height is limited (A) to the grasping reach of the smallest users if controls are placed in the upper regions and (B) to the visual fields if only displays are placed in the upper regions.	(1) For the "standing only" console, the maximum height of the console should be limited to either (A) that height to which the smallest user (e.g., 5th percentile) can conveniently reach, or (B) to the highest level on the display panel which is tangent to the area permitting a viewing angle of 45° or greater. (2) For the "sitting only" console, the maximum height of the console is limited to either (A) that height to which the smallest user (e.g., 5th percentile) can conveniently reach from a sitting position, or (B) the highest level on the display panel which is tangent to the area permitting an angle of 45° or greater. (3) For the "standing and sitting" console, the maximum height of the console should be limited to either (A) that height to which the smallest user (e.g., 5th percentile) can	(1) The maximum height for "standing only" consoles without vision over the top should be approximately 183 cm. (72 in.). (2) The maximum height for "sitting only" consoles without vision over the top should be approximately 130 cm. (51.5 in.), when the height of the seat is set at 46 cm. (18 in.).

Table B-12. Continued

Summary of the Discussion and Recommendations of the Main Design Features of a Console/Workplace for the Seated Operator

Dimension	Discussion	Remarks	Previous Recommendations
		conveniently reach, or (B) to the highest level on the display panel which is tangent to the area permitting an angle of 45° or greater. In the above cases, maximum console height is limited to the value of the smallest user's (e.g., 5th percentile) reach volume (sitting or standing depending on type of console), if controls are to be located in the upper regions.	

Table B-12. Continued

Summary of the Discussion and Recommendations of the Main Design Features of a Console/Workplace for the Seated Operator

Dimension	Discussion	Remarks	Previous Recommendations
Maximum height of the console with vision over the top	The maximum height of the console depends on whether the user is "sitting only," or both "standing and sitting". The maximum height is limited by the eye height of the smallest users.	(1) For the "sitting only" console, the maximum height of the console is limited by the value of the smallest user's (e.g., 5th percentile) eye-height sitting, plus the upper range of the adjustment of the seat. Consequently, the proportion of the population greater than the minimum percentile will be able to see over the console.	(1) The maximum height for "sitting only" consoles with vision over the top should be approximately 121 cm. (47.5 in.).
		(2) For the "standing and sitting" console, with vision over the top for the standing position only, the maximum height of the console is limited by the value of the smallest user's (e.g., 5th percentile) standing eye-height plus shoe height. This would permit a proportion of the population greater than the minimum to see over the console without materially altering their posture. The seat height should be positioned so that the eyes of the users with maximum (e.g., 95th) percentile eye-height sitting and the the eyes of the users with	(2) The maximum height for "standing and sitting" consoles with vision over the top for the standing position only should be approximately 157 cm. (62 in.) when the height of the seat is set at 72 cm. (28.5 in.)

Table B-12. Continued

Summary of the Discussion and Recommendations of the Main Design Features of a Console/Workplace for the Seated Operator

Dimension	Discussion	Remarks	Previous Recommendations
		minimum (e.g., 5th) percentile eye height standing are at the same level. (3) For the "standing and sitting" console with vision over the top for both positions, the seat height should be positioned so that the eyes of the largest user (e.g., 95th percentile) eye-height sitting is in the same position as the eyes of the smallest user (e.g., 5th percentile) eye-height standing. The console height is limited by the value of the smallest user's (e.g., 5th percentile) eye-height sitting, plus the upper range of the adjustment of the seat.	(3) The maximum height for "standing and sitting" consoles with vision over the top for both positions should be approximately 147 cm. (58 in.) when the height of the seat is set at 72 cm. (28.5 in.).

Table B-12. Continued

Summary of the Discussion and Recommendations of the Main Design Features of a Console/Workplace for the Seated Operator

Dimension	Discussion	Remarks	Previous Recommendations
Maximum console panel breadth	The maximum console panel breadth is limited (A) to the grasping reach of the smallest users if controls are placed in these areas and (B) to the visual fields of all users if only displays are placed in these areas.	If both controls and displays are to be placed on the console, the maximum console panel breadth is limited by the percentage of the panel area permitting a viewing angle of 45° or greater for for displays and which is in the grasping reach of the smallest user (e.g., 5th percentile) for controls. If only controls are to be placed on the panel, the maximum console panel breadth is limited by the percentage of panel area within reach of either hand of the smallest user (e.g., 5th percentile). If only displays are to be placed on the panel, the maximum console breadth is limited by the percentage of panel area permitting a viewing angle of 45° or greater.	The maximum console panel breadth should be approximately 91 cm. (36 in.).

Table B-12. Concluded

Summary of the Discussion and Recommendations of the Main Design Features of a Console/Workplace for the Seated Operator

Dimension	Discussion	Remarks	Previous Recommendation
Optimum panel angle	The panel angle is based on two considerations: (A) it should permit adequate vision, and (B) it should be within convenient grasping-reach of a large portion of the user's population, if the area is used for control. As the angle increases, the upper part of the panel is displaced farther away from the operator and becomes less convenient for the smaller users to reach.	If the panel is to be used for controls, the panel angle should be 15^{o} since this angle is the maximum that accommodates adequately the reach of the smallest (e.g., 5th percentile) operator. If the panel is not to be used for controls, a greater angle than 15^{o} may be used. *Note: The upper segment's angle should be such as to be normal to the user's line-of-sight.	If the panel is used only for displays, an angle up to 25^{o} may be used. If the panel is used for controls, the maximum panel angle should be 15^{o}.

located 10 inches from the eye position and 6 inches above elbow height. Sitting is mandatory for this type of task. For precision work, the work surface should be 2 inches above the elbow height. For writing or light assembly work and for course or medium manual work, the work surface height should be, respectively, 4 inches and 8 inches below the elbow height (Ayoub, 1973).

<u>Maximum height of the console</u>

The maximum height of the console depends on whether vision is required over the top of the console. A second requirement is whether the user will sit only, stand only, or alternately sit and stand (Kennedy & Bates, 1965). If vision is not required over the top of the console, the maximum height is limited to the grasping reach of the smallest users if controls are placed in the upper regions of the console, and to visual fields of the users if only displays are placed in the upper regions. If vision is required over the top of the console, the maximum height of the console is limited to the eye height of the smallest users. For the sitting only console, the maximum height of the console is limited by the value of the smallest users' eye height sitting. The maximum height of the standing only console is limited by the value of the smallest users' standing eye height (Kennedy & Bates, 1965).

<u>Maximum console breadth</u>

The maximum console breadth is limited by the grasping reach of the smallest users if controls are placed in these areas and/or to the visual fields of all users if only displays are positioned in these areas (Kennedy & Bates, 1965). The work surface width is limited by the reach of the smallest users.

Optimum panel angle

The panel angle should permit adequate vision and, if controls are placed in the upper regions, of the panel angle, should be within convenient grasping-reach of the user's population. As the panel angle increases, the upper part of the panel is displaced farther away from the operator and becomes less convenient for the smaller users to reach. At angles greater than 15°, the upper section of the panel becomes inaccessible to the smaller operators unless he bends forward at the hips (Kennedy & Bates, 1965).

Discussion

In another section, the literature collected and annotated by Dannhaus, Dixon, Adams, & Roth (1976) has been partially integrated. Brief abstractions of the design features, remarks and previous recommendations are presented in tabular format. The tabular format is provided to permit quick reference for those interested (e.g., designers) in salient design considerations, their logical basis, or as a brief survey of previous quantitative and qualitative recommendations. The text contains a fuller, more comprehensive discussion of each design feature and is suggested reading prior to first use of the tables. The text and tables are an incomplete integration, however, because of lack in current data.

In initiating this report, it was hoped that a complete integration of the literature would be possible. In particular, it was hoped that recommendations for all relevant variables could be made which would meet the 90 per cent accommodation requirement of the current military standard, MIL-STD-1472B (DoD, 1975). Lack of systematic collections of current data and failure of previous anthropometric surveys to collect relevant design variables (e.g., L-5 vertebra, T-12 to L-5 distance height, intra-iliac crest width) have frustrated the hope for complete integration. The current study does, however, provide a basis for developing a complete integration. Previous recommendations have been collected and presented in a manner to facilitate quick reference. Relevant workplace anthropometric variables have been identified and related to specific workplace dimensions*[1]. The current report, therefore, provides the means for partial evaluations of a proposed workplace design and is a step toward a complete workplace design integration.

RECOMMENDATIONS

Based on the finding of this report, the following recommendations are made:

1. Systematic collection of relevant current data, as noted in the text, should be made in a format suitable for updating.
2. All workplace anthropometric data, as noted in the text, should be collected upon current relevant populations.

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[1] A model for integrating these variables, it is noteworthy, has been illustrated in a previous report (Bittner, Dannhaus, and Roth). This report shows that at least the 1.75th-to-98.25th percentile range must be accommodated where a conventional "one-dimension-at-a-time" design approach is employed to accommodate 90 per cent of the potential user population.

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SECTION C

WORKPLACE-ACCOMMODATED PERCENTAGE EVALUATION: Model and Preliminary Results

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SECTION C

CONTENTS

SUMMARY

Section C describes a procedure for determining the percentage excluded from a seat-console design, given the percentage excluded on individual dimensions. In addition, cutoff percentages were established to ensure accommodation of approximately 90 percent of the total potential user population.

Seven critical anthropometric variables for seat-console design were identified and decision flowcharts for these anthropometric variables were developed. A "computerized accommodated percentage evaluation (CAPE)" model was used to determine the percentage excluded on the total design of a seat-console as critical limits were imposed on each individual anthropometric dimension. Where 90 percent of the potential user population is to be accommodated by the total seat-console design, it was recommended that at least the 1.75th-to-98.25th percentile range must be accommodated where a conventional "one-dimension-at-a-time" design approach is employed.

Results of this report are applicable to meeting MIL-STD-1472B criteria for accommodating 90 percent of the potential user population.

INTRODUCTION

Background

Traditionally, workspaces have been designed to accommodate individuals with anthropometric features within specified percentile ranges. In setting design limits it is frequently the practice to use a range from the 5th to the 95th percentile values for critical body dimensions (Morgan, et al., 1963; McCormick, 1970; Van Cott et al., 1972; Roebuck et al., 1975). For any body dimension, the 5th percentile value indicates that 5 percent of the population is equal to or smaller than that value, and 95 percent is larger. Likewise, the 95th percentile value indicates that 95 percent of the population is equal to or smaller than that value and 5 percent is larger. Theoretically, 90 percent of the total user population will be accommodated for a given dimension in the workplace.

Problem

When two or more dimensions are used simultaneously as design parameters, as is usually the case in designing workspaces, the problem becomes more complex. Although the proportion of the population accommodated is an important design criterion, it is not readily available. The Human Engineering Criteria for Military Systems, Equipment, and Facilties (MIL-STD-1472B), for example, requires that "where two or more dimensions are used simultaneously as design parameters, the central 90 percent of the total user population must be accommodated" (DoD, 1974, p. 99). Thus to meet this standard all equipment must be designed to accommodate 90 percent of a user population jointly on <u>all</u> anthropometric variables. Conventionally, designers have used the 5th-to-95th-percentile range for each individual dimension used in a workspace design. According to Moroney and Smith (1972), the untenable assumption underlying the "one-dimension-at-a-time approach" is that individuals with one anthropometric characteristic outside tolerance limits will exceed the established range on all other anthropometric features. When such a procedure is employed, the accommodated proportion of the potential user population (P_a) is not readily apparent because of the correlations between features. In fact, Daniels (1952) and Moroney and Smith (1972) employing large-scale empirical studies demonstrated that the proportion of the potential user population exclusion ($1-P_a$) may be quite large -- findings supported by an analysis in Roebuck et al. (1975). Moroney and Smith for example, examined thirteen anthropometric features related to cockpit design for 1547 naval aviator personnel. Employing the 5th-to-95th percentile critical design limits for all thirteen dimensions, 52% of the population was excluded; while for the critical design limits of 3rd-to-98th percentile, over 32% of the original population was excluded. In view of the existing requirement of MIL-STD-1472B that equipment must be designed to accommodate the central 90 percent of the proposed user population, more stringent design limits than the conventional 5th-to-95th percentiles need to be determined.

Purpose

The purposes of this report are:

1. To describe a procedure for determining the percentage excluded from a seat-console design given the percentage excluded on individual dimensions.
2. To establish, for a general seat-console design, cutoff percentages to ensure accommodation of approximately 90% of the total potential user population.

METHOD

Approach

The determination of the percentage excluded by the total seat-console design from the percentages excluded on the individual dimensions was conducted in two phases. During the first phase, the critical anthropometric variables for a general seat-console design were identified. In the second phase, a computerized accommodated percentage evaluation (CAPE) model (Bittner, 1974, 1975) was employed to determine the percentage excluded on the total design of a seat-console as critical limits were imposed on each individual anthropometric dimension.

Analysis of the Critical Anthropometric Dimensions

In an earlier report, anthropometric dimensions considered important to the general seat-console integration design were presented (cf. Dannhaus et al., 1976). These were evaluated, in the present study, in relation to a basic and very widely used seat-console design. The design selected was a console to be used in a sit-only position in which vision was not required over the top of the console. In addition, little or no torso movement was assumed to be required of the user of the console.

A flow diagram of relevant anthropometric dimension restrictions which limit the accommodation of users in an adjustable chair is presented in figure C-1. It should be noted that the critical limits (e.g., $\leq$ 3rd, $\leq$ 5th, or $\leq \alpha$ percentile and $\geq$ 95th, $\geq$ 98th, or $\geq 100-\alpha$ percentile) should not be applied at both extremes for all individual dimensions. For example, the dimensions of seat pan width may not accommodate users with large hip breadths, but it will accommodate all user's hip breadths regardless of how small (i.e.,

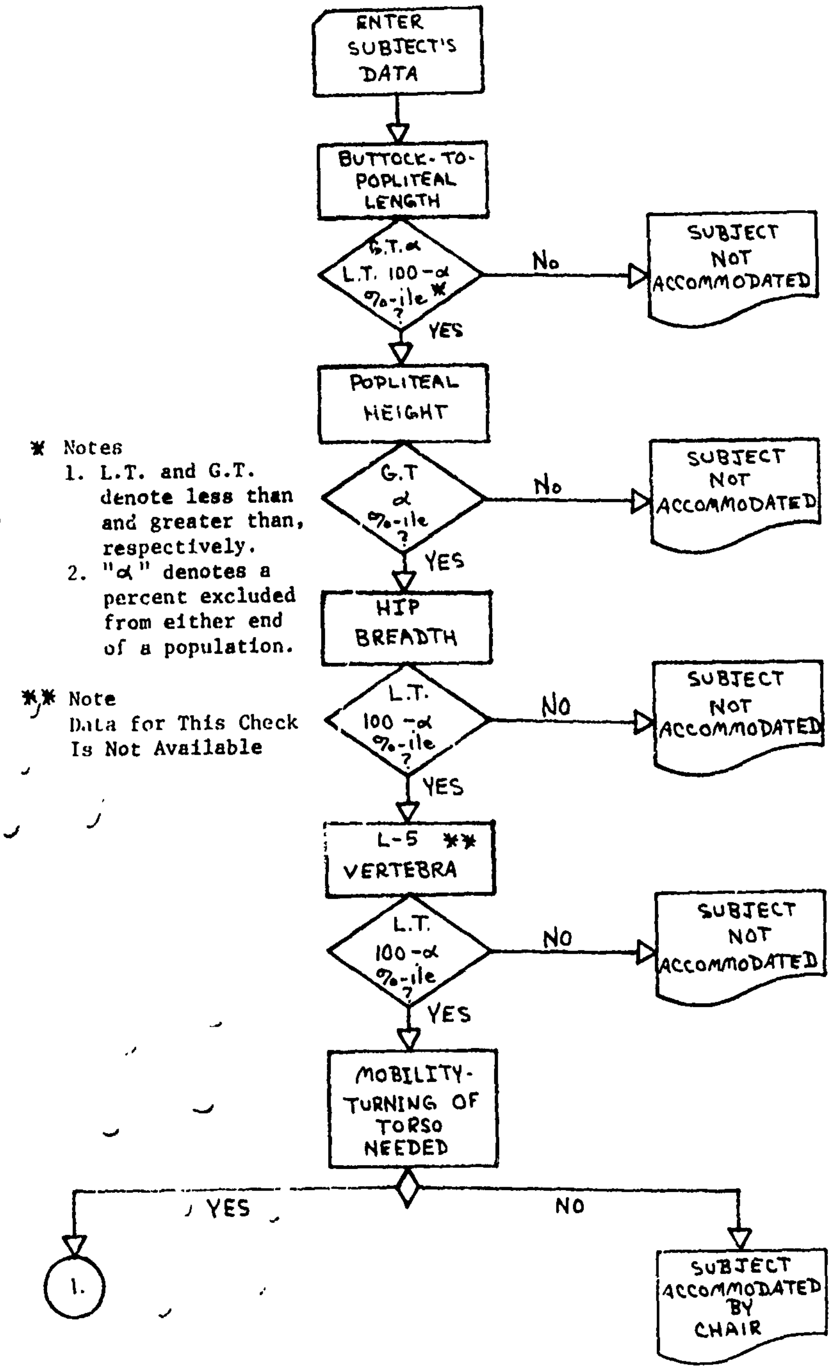


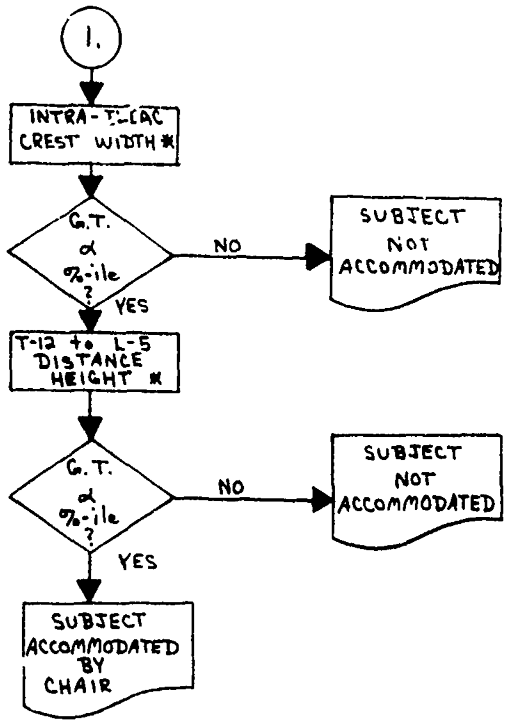
Figure C-1. Flow Diagram of Adjustable Chair Accommodation Checks for a Sample Subject.

hip breadth $\leq$ 100-α percentile). Contrarily, seat pan depth may not accommodate users with small buttock-to-popliteal lengths, but the seat pan depth should accommodate all other users' buttock-to-popliteal lengths (i.e., buttock-to-popliteal lengths $\geq \alpha$ percentile).

The first anthropometric dimension examined was buttock-to-popliteal length. If potential users' buttock-to-popliteal length were not greater than α percentile, then they were judged not accommodated by the depth of the seat pan. The second variable considered was popliteal height which corresponds to the height of the seat pan. Potential users who were not accommodated were those users whose popliteal height was less than α percentile. The next dimension examined was hip breadth. Potential users whose hip breadths were greater than 100-α percentile were not accommodated by the seat pan width. The fourth dimension was the L-5 vertebral height which corresponds to the heighth of the space between the seat pan and the bottom edge of the back rest. Because data for the relationship of the L-5 vertebral height with other dimensions were not available, cervical height correlation were used in place of L-5 correlations. Hence, users whose "estimated L-5 height" was greater than 100-α percentile were judged not accommodated by the space between seat pan and back rest.

As the seat-console design selected for analysis was one in which little or no movement of the user was required only the above four relevant anthropometric dimensions for the seat were analyzed. If movement of the user will be required at least two more anthropometric dimensions must be analyzed, viz., intra-illac crest width and T-12 to L-5 distance (see firgure C-2).

Figure C-3 shows the flow diagram of anthropometric dimension exclusion procedures relevant for a sit-only console in which vision over the console



* Note
Data for These
Checks Are Not
Available

Figure C-2. Continuation of Flow Diagram for Adjustable Chair Checks When Mobility-Turning of Torso Required.

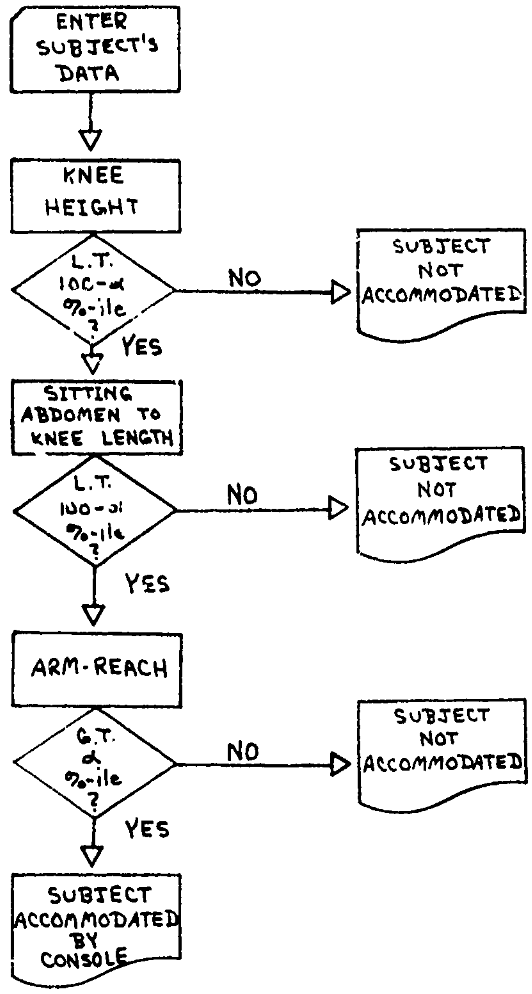


Figure C-3. Flow Diagram of Sit-Only No-Vision Over Console Checks for a Sample Subject.

is not required. The first anthropometric dimension examined was sitting knee height which corresponds to vertical leg room underneath the console desktop. Potential users whose sitting knee height exceeded the 100-α percentile were not accommodated by the vertical leg room underneath the desktop. The second dimension considered was the sitting abdomen-knee length. The abdomen-knee length dimension was associated with the depth needed to accommodate the insertion of the knees under the desktop so that the abdomen may be in contact with the desk front. If users' abdomen-knee lengths were greater than 100-α percentile, then the users were judged not accommodated on this dimension. The last dimension analyzed was the functional arm-reach. Potential users whose functional arm-reach was less than α percentile were not accommodated by the console design.[1]

Model

The second phase of the study was concerned with estimating the percentage of users that would be excluded from the total seat-console design when respective α or 100-α percentiles were applied individually to each of the seven anthropometric dimensions. To make this estimate, an implicit multivariate normal model was constructed for the seven anthropometric variables discussed above, and exercised by a Monte Carlo computer routine developed by Bittner (1974, 1975)[2]. The correlation matrix used for this model is

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[1] Appendix A contains the definiton of several anthropometric variables, including the seven identified above, and tells how each variable is measured.

[2] An "implicit normal model", defined in Bittner and Moroney (1974), assumes that monotonic transformations of the marginal distributions of variables to normal, transforms their joint distribution to multivariate normal.

given in table C-1 and includes variables useful in a broad range of seat and console analyses--beyond the scope of current effort.[3] The α and 100-α percentiles used as screening criteria were the following: (1) 5th or 95th percentile limits, (2) 4th or 96th percentile limits, (3) 2.5th or 97.5th percentile limits, (4) 1.75th or 98.25th percentile limits, and (5) 1.15th or 98.5th percentile limits. An odd prime number starting seed (IX) was arbitrarily set at 41 for all runs (see Bittner, 1974 for discussion). The number of Monte Carlo cases for all screening simulations was set at 400.

RESULTS

Figure C-4 represents the percentage of users excluded from the total design as a function of the percentage of (400 sample) users excluded on each individual dimension. It can be observed that when the 5th or 95th percentile critical limits were applied, about 25 percent of the potential user population was excluded on one or more of the seven relevant dimensions. Even when the critical limits were made more stringent (to 2.5th or 97.5th percentiles), approximately 15 percent of the user population was excluded from the total design. Ten percent of the potential user population, the design limit for MIL-STD-1472B, was excluded from the total design when the critical limits were set at 1.75th or 98.25th percentiles.

A second degree polynomial was fit to the data shown in figure C-4 (r = 0.999) to provide an approximation of the continuous trade off between percent

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[3] These correlations were extracted and/or derived from those of White et al. (1971) and believed more representative of the general military population than others which were available.

Table C-1.

Anthropometric Dimensions Important in Seat-Console Design and Their Intercorrelations

Dimension	Variable											
	1	2	3	4	5	6	7	8	9	10	11	12
1 Stature	1	.977	.776	.753	.878	.808	.684	.801	.627	.179	.331	.503
2 Cervical Height		1	.726	.702	.898	.803	.705	.829	.626	.217	.364	.481
3 Sitting Height			1	.906	.507	.435	.310	.429	.362	.197	.373	.212
4 Eye Height (sitting)				1	.488	.418	.295	.410	.342	.186	.355	.199
5 Knee Height (sitting)					1	.843	.718	.826	.675	.217	.319	.460
6 Popliteal Height (sitting)						1	.619	.653	.574	-.060	-.006	.430
7 Buttock-Popliteal Length							1	.853	.538	.205	.316	.486
8 Buttock-Knee Length								1	.610	.334	.453	.500
9 Functional Reach									1	.163	.216	.328
10 Chest Breadth										1	.663	-.280
11 Hip Breadth (sitting)											1	-.184
12 Abdomen-Knee Length (sitting)												1

excluded on individual dimensions (x) and the total percent excluded (P_a). The resulting equation was $P_a = 3.50 + 8.583\,x - 0.583\,x^2$ and had a standard error of 0.28. This equation, over the range 1 to 5 percent exclusion on individual dimensions, summarizes the data of figure C-4.

DISCUSSION

This report demonstrates that the critical limits for each individual dimension must be more stringent than the limits of 5th and 95th percentiles. MIL-STD-1472B (DoD, 1974) states that where two or more dimensions are used simultaneously as design parameters, the central 90 percent of the total user population must be accommodated. Using a seat-console design with fewer restrictions than other types, it was found that about 25 percent and 15 percent of the user population would not be accommodated by a design using 5th and 95th or 2.5th and 97.5th, respectively. It was also found that to ensure accommodations of 90 percent of a total potential user population for the very basic seat-console design, analyzed in this report, the critical limits of each of the seven anthropometric variables must be set at 1.75th and 98.25th percentiles.

As the seat-console design requirements are increased (e.g., sit/stand with vision over the top of the console) and consequently more anthropometric variables are employed, the critical limits of each individual anthropometric variable may have to be set at more stringent limits than found in this report. Likewise, in designs where some accommodations are fixed at specific percentile values (e.g., many standard consoles accommodate only 5th percentile reaches), non-fixed variables would require more stringent limits if 90 percent total accommodation is to be realized. In these cases analyses

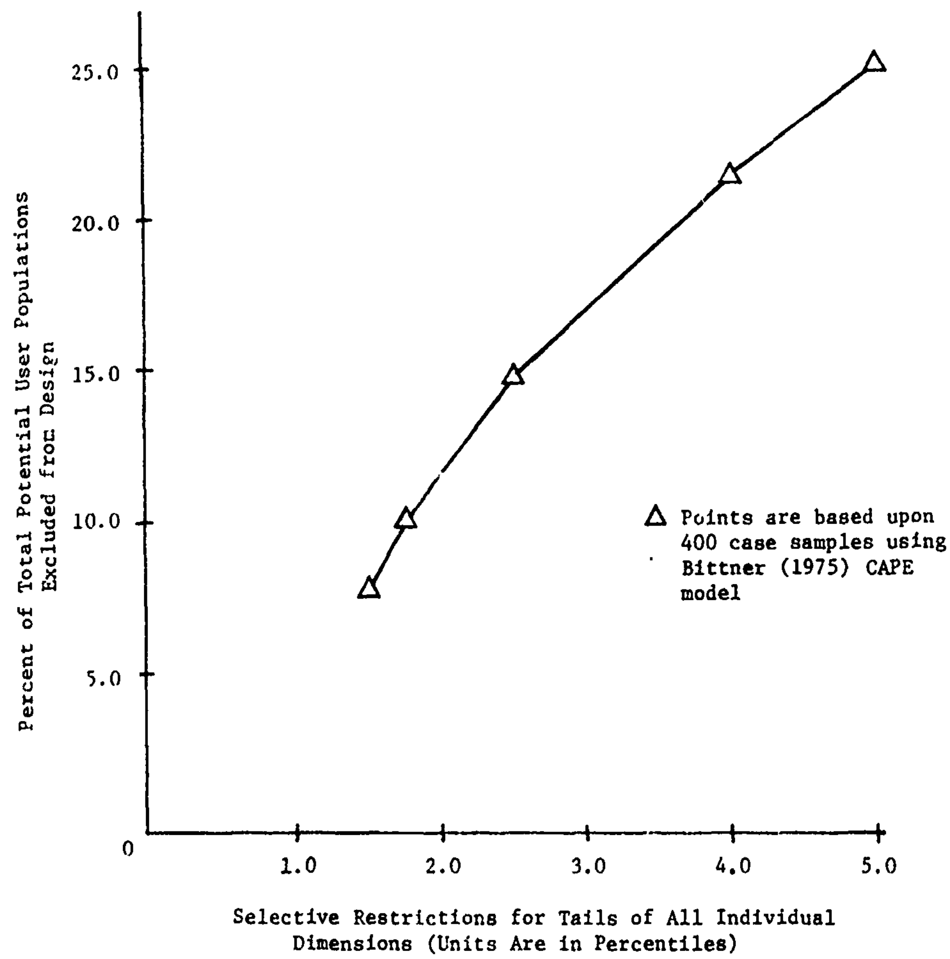

Figure C-4. Demonstration of Accommodated Percentage Workplace Analysis: Sit-Only No-Vision-Over-Console with Minimum Torso Turning Required.

similar to that used herein could be emphasized and can be recommended.[4] However, adoption of the 1.75th and 98.25th percentile for adjustments would provide immediate improvement toward the goal of the MIL-STD-1472B.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, the following conclusions have been reached:

(1) In order to accomplish detailed analyses of accommodation of potential users by the total design, it is necessary for the designer to utilize a model such as the one developed by Bittner (1974, 1975).

(2) There is an apparent shortage and weakness in the available anthropometric data. For example, there is little data available on the height of the L-5 vertebra, the intrailiac crest width, or the T-12 to L-5 distance.[5]

(3) More stringent critical limits than the conventional 5th and 95th percentiles must be set on each individual anthropometric dimension, if 90 percent of the potential user population is to be accommodated by the total seat-console design. For purposes of seat-console design, at least the 1.75th through 98.25th range must be accommodated if a conventional "one-dimension-at-a-time" design approach is employed.

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[4]The correlation matrix provided in table C-1 and the interactive nature of the CAPE model (Bittner, 1975) makes this an easy possibility.

[5]Data are currently being developed by Texas Tech University which should at least partially meet these needs.

Appendix

Definitions of Anthropometric

Features

Definitions of Critical Anthropometric Dimensions

Stature	Subject stands erect, looking straight ahead. The measurement is the vertical distance from the floor to the top of the head.
L-5 Height	Subject sits erect, looking straight ahead, with knees and ankles forming right angles. The measurement is the vertical distance from the sitting surface to the spine of the L-5 vertebra.
Sitting Height	Subject sits erect, looking straight ahead, with knees and ankles forming right angles. The measurement is the vertical distance from the sitting surface to the top of the head.
Eye Height (Sitting)	Subject sits erect, looking straight ahead, with arms hanging loose with forearms and hands extended parallel to sitting surface. The measurement is the vertical distance from the sitting surface to the inner corner of eye (inner canthus).
Sitting Knee Height	Subject sits erect, with knees and ankles forming right angles. The measurement is the vertical distance from the footrest surface to the upper most point on the knee.
Popliteal Height	Subject sits erect, with knees and ankles forming right angles. The measurement is the vertical distance from the footrest surface to the underside of the right knee (popliteal area).
Buttock-Popliteal Length	Subject sits erect, with knees and ankles forming right angles. The measurement is the horizontal distance from the plane of the rearmost point on the buttocks to the back of the lower leg at the knee.

Buttock-Knee Length	Subject sits erect, with knees and ankles forming right angles. The measurement is the horizontal distance from the plane of the rearmost point on the buttocks to the front of the knee (knee-cap).
Functional Reach	Subject stands erect in corner, with shoulders against rear wall, right arm extended horizontally along side wall with thumb and forefinger together. The measurement is distance from the wall to top of thumb.
Chest Breadth	Subject stands erect, breathing normally, arms hanging naturally at sides. The measurement is the horizontal distance across the chest at nipple level.
Hip Breadth (Sitting)	Subject sits erect, with knees and ankles forming right angles, and the knees and heels together. The measurement is the maximum horizontal distance across the hips.
Sitting Abdomen-Knee Length	Subject sits erect, with knees and ankles forming right angles. The measurement is the horizontal distance from the plane of the outermost point of the abdomen to the front of the knee.

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SECTION D

METHODOLOGY AND REACH PROFILES FOR RESTRAINED AND UNRESTRAINED SEATED OPERATORS

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SECTION D

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CONTENTS

SUMMARY

The approach used to measure reach in many anthropometric studies has been to take only a single measure of maximum reach--measuring only the maximal forward reach of the preferred arm from a vertical surface with a standing (erect) subject.

The present work considers this method to be inappropriate for the measurement and/or extrapolation of reach envelopes for design purposes. More sophisticated methods for the measurement of reach envelopes have been developed over a period of years. A criticism of all these methods, however, is that they were designed for static measurement of reach capability and, frequently, are limited with respect to accuracy.

Section D describes the development and validation of a reach apparatus that would overcome the above criticisms. Summary statistics for reach envelopes as well as graphic plots of the reach envelopes are presented.

AYOUB REACH ANTHROPOMETRIC (ARA) FACILITY

Background

The approach which has typically been used to measure reach in many classic anthropometric studies has been to take only a single measure of maximum reach. This involves measuring only the maximal forward reach of the preferred arm from a vertical surface with a standing (erect) subject. Design recommendations based on extrapolations from such a single measurement are necessarily erroneous for the following reasons: first, no information is provided regarding the characteristics of movement in various horizontal and/or vertical planes of the reach point. Secondly, the measurement is typically made from a wall surface rather than from a landmark on the body usable as a reference point, such as the acromiale. The present work, therefore, considers this method to be inappropriate for the measurement and/or extrapolation of reach envelopes for design purposes.

More sophisticated methods for the measurement of reach envelopes have been developed over a period of years. Wright (1963) describes an apparatus developed by Frankenstein and Sons capable of measuring the entire reach envelope by mechanical means. This method, while involving the use of a cumbersome framework, is capable of rotation about the subject's neutral seat reference point (SRP) and can measure reach at about five-degree arc increments. The major disadvantage of this apparatus is that it is capable of yielding only static measures of reach capability.

Adaptations of the Frankenstein apparatus have appeared in several recent studies. Kennedy (1974) described an adaptation of Frankenstein's apparatus with minor modifications to the original design. Laubach and Alexander (1974) employed an apparatus similar to the Frankenstein apparatus, which employed potentiometric measurement of reach displacement rather than calibrated rods, thus giving somewhat greater accurac . Bohn and Gregoire (1974) also developed a similar computerized mod fication of the Frankenstein apparatus.

Another system of reach measurement similar to that developed by Morant (1945) was used by Gregoire (1973), in which the subject's reach was made against a ruled background grid. Reach was measured by means of a differentially ruled foreground grid comparison.

Ayoub Reach Apparatus (ARA)

A criticism of all these methods of reach envelope measurement is that they were designed for static measurement of reach capability, and, frequently are limited with respect to accuracy.

The purpose of the present report is to describe the development and validation of a reach apparatus that would overcome the above criticisms of methods of reach measurement. The present device, identified herein as the Ayoub Reach Anthropometer (ARA, is a modification of a design by Ayoub (1972) which in its original form has been previously used in studies at Texas Tech University (Raheja, 1966; Taraman, 1973; Petruno, 1972; Ayoub, 1972). The ARA consists of a three-axis potentiometer system capable of sensing position or motion in three-dimensional space. The axes measured by the potentiometers are vertical (elevation) angle from the apparatus center, horizontal (azimuth) angle from the apparatus center, and radius displacement of the device arm. The apparatus is shown in figure D-1.

For the purposes of the present study the device used by Ayoub (1972) was modified in several ways. First, the length of the rod measuring radius displacement was increased to about two meters (6.5 feet) in order to allow for measurement of greater amounts of displacement and a wider range. Second, the vertical (elevation) angle allowable in the device was increased by fitting a modified (deeper) yoke in which the apparatus pivots on the vertical axis.

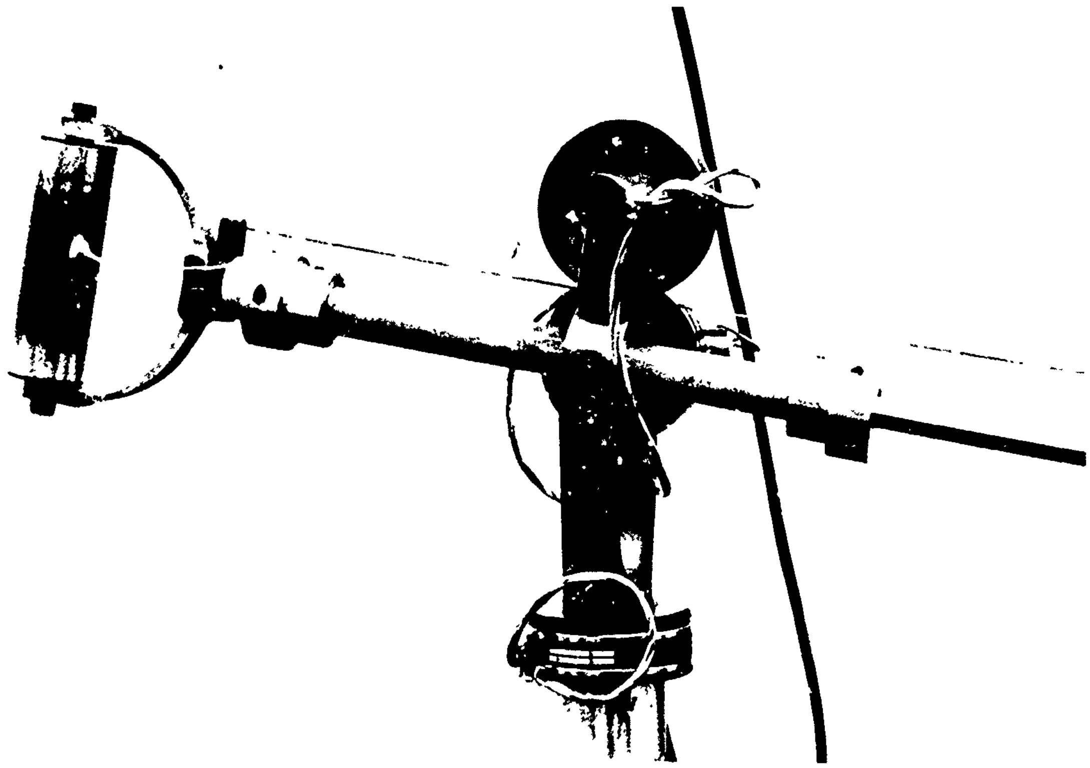


Figure D-1. Ayoub Reach Anthropometer (ARA).

A third modification involved fitting the apparatus with a rotatable handle and yoke for the subject's grip for grip-center reaches. With these modifications, the ARA becomes a versatile apparatus for describing a subject's reach envelope accurately and completely.

Another feature of the Ayoub Reach Facility (ARF) is a locally-fabricated adjustable chair (shown in figure D-2). This chair features an adjustable backrest angle (90-150 degree range), an adjustable backrest height above the seat pan (0-25 cm above SRP), adjustable swivel position (360 degrees) and an adjustable seat height (47.5 cm to approximately 130 cm). The chair was not adjusted in this study but was set at a fixed height for subjects; however, its adjustability will be useful in later studies investigating the effects of seat back angle on the reach envelope. Also fitted to the chair was an adjustable footrest which was adjusted to accommodate the subjects. Seat height in the present study was 47.7 cm, backrest angle was 103 degrees, height of the seat back from the seat pan was 13 cm and the seat was rotated so that its forward plane was the same as that described by the SRP and the center of motion of the ARA. Also incorporated in the chair design were adjustable lap and shoulder belts for restraint of the subject in a manner similar to that of a fighter cockpit. The seat reference point is located 12. 7 cm forward from the center of the ARA vertical post. Figure D-3 shows a subject seated in the chair under maximum shoulder-harness and lap belt restraint.

In order to define the reach positions for the reach protocols, an apparatus was fabricated for this purpose. This apparatus consists of a horizontal, rotatable bar suspended from the ceiling of the experimental room, supporting a vertical length of light chain. The center of rotation of this bar is placed directly above the SRP. Also part of the alignment system are a number of azimuth-reference lines inscribed upon the floor of the experimental room and on the support plate of the positioning apparatus. Azimuth alignment of this

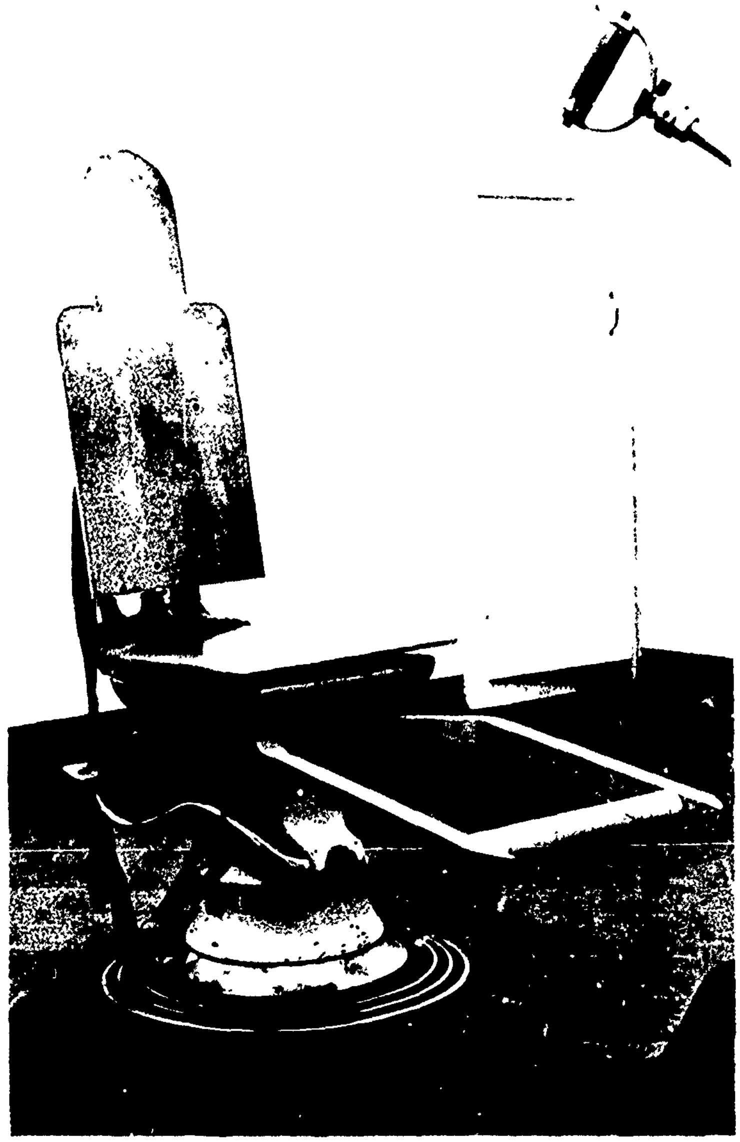


Figure D-2. Ayoub Reach Facility (ARF) Adjustable Chair.

Figure D-3. Subject Seated in ARF Chair Under Maximum Restraint Making Reach with ARA.

device consisted of aligning the support (ceiling) bar with the overhead reference lines and aligning a plumbbob at the end of the chain with the floor reference lines. This method results in an azimuth-angle accuracy of $\pm$ 1 degree relative to the SRP-ARA-center of rotation (the 0, 0, 0 point of the appratus itself). Elevation alignment marks (or tags) are referenced from the Vertical-Angle Reference Point (VARP), which is an imaginary point located in space above the SRP and at the same height as the center of rotation of the ARA.

Angles referenced by this apparatus range from +120 degrees to -45 degrees in the azimuth plane and from -60 degrees to +75 degrees in the elevation plane. The accuracy of elevation angles as well as azimuth angles was found to be about $\pm$ 1 degree. Figures D-4 and D-5 show the alignment apparatus.

Power for the potentiometers of the ARA is supplied by regulated $\pm$ 10 volt power supply, attenuated by the operational amplifiers of an analog computer. Signals from each potentiometer and from the experimenters' sample-request switch are cabled to the analog-to-digital converter of a PDP-12 computer (see Figure D-6).

Upon receiving a sample-request pulse from the experimenters' switch, the computer samples and digitizes the potentials from each channel of the A-to-D converter and stores the digitizer information in core data buffers. These potentials represent the azimuth, elevation and radius for each point. (See Appendix A for flow charts and listings of the computer software employed). Upon completion of an entire 121-point reach protocol, the computer automatically stores the three data buffers on magnetic tape for later decoding.

The major limiting factor on the accuracy of the above described system is the resolution ability of the analog-to-digital converter involved in digitizing the data. The standard ($\pm$ 1 volt range) units used with the PDP-12 are 12-bit

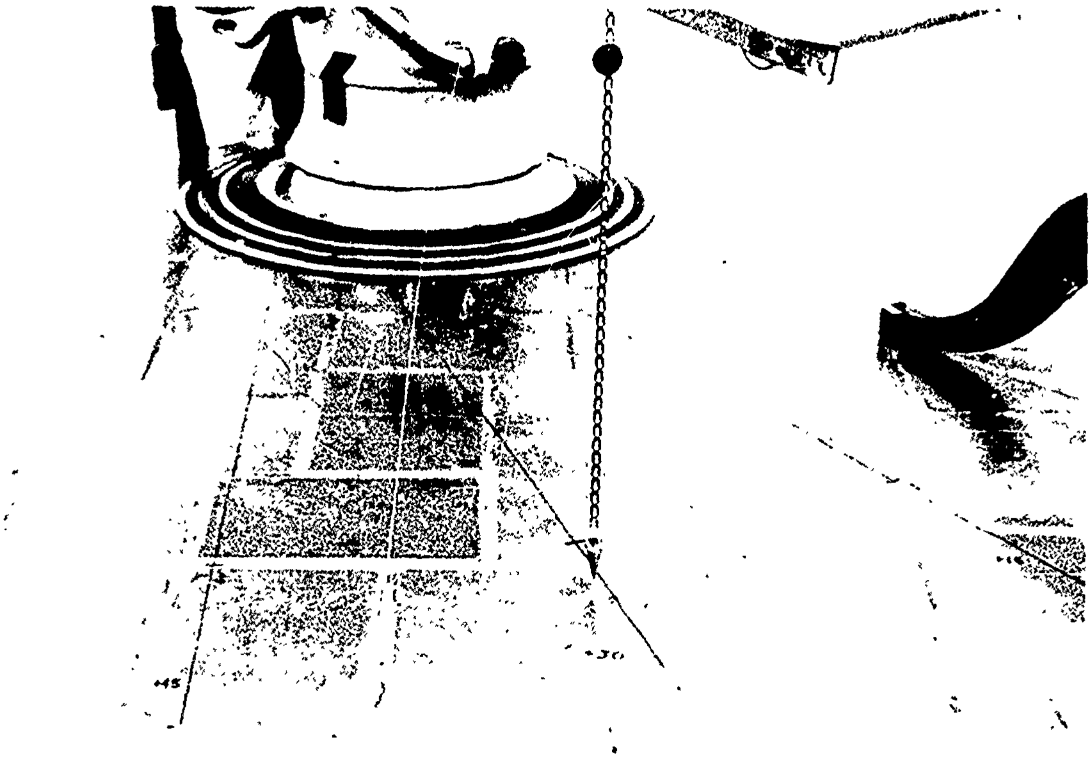


Figure D-4. Plumbline and Azimuth Lines Used for Alignment.

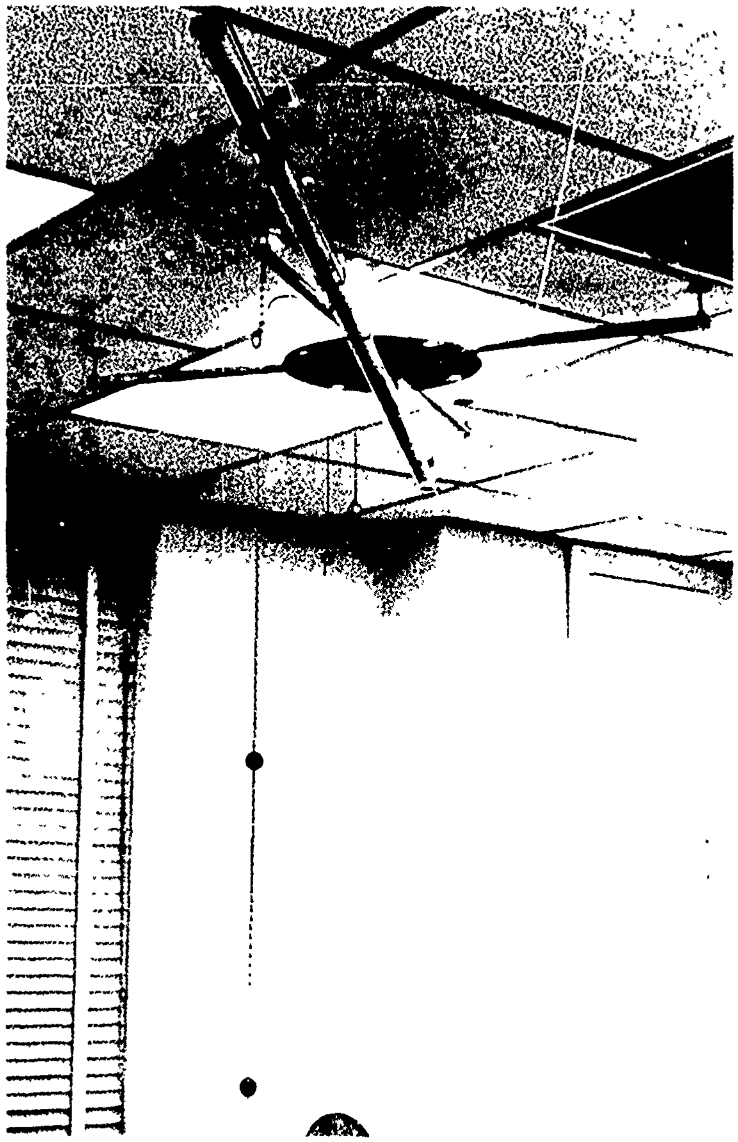


Figure D-5. Ceiling-Mounted Portion of Alignment System Showing Rotating Bar and Plumbline.

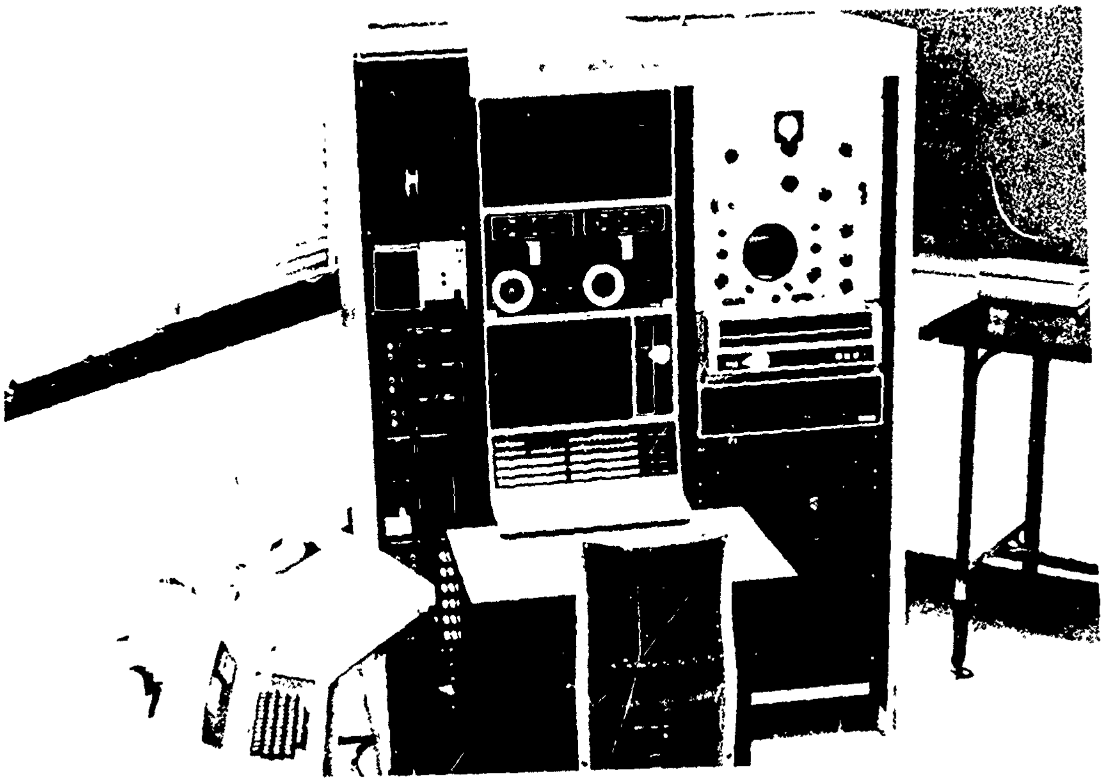


Figure D-6. PDP-12 Computer Facility.

converters, but three bits are used for sign designation in the resultant digital word, thus giving only 9-bit accuracy, or 1/1024 of the entire range of the converter. This translates into a resolution of .187 degrees for the potentiometers used for ARA angular measurement of azimuth and elevation and to .125 cm for the potentiometers used for radius-arm displacement measurement. Due to the limited range or resolution of the converter with the radius arm, an offset center (60 cm from the end of the arm nearest the subject) was used and corrected with a software routine to compensate for the "lost" 60 cm.

The linearity of potentiometers used in a system such as this one also poses a potential problem, especially if the potentiometers are applied across much of their [illegible]tal range. Some over-tolerance nonlinearity was found in the potentiometers used in the ARA. The degree of nonlinearity for each potentiometer was determined across the needed ranges, and software routines incorporated in the decoding programs were used to correct for this problem.

Resolution and accuracy measures were taken prior to data collection and found to be adequate after having been digitized and decoded. Accuracy was found to be within the 1% maximum tolerable error for each of the measurement axes. The reliability of the system was also tested. Prior to data collection, repreated measures were taken to 20 fixed points with known spatial coordinates and for two subject protocols using the same subject with the same experimenters taking reach measures. Correlations between one measurement and its counterpart on another reach protocol or positioning series were found to be greater than .99 for all test protocols.

Method

Subjects:

Subjects consisted of 25 males, ages 18 to 42 years old, and 24 females ages 18 to 22 years old. Subject weights ranged from 45.45 kg to 71.48 kg for females and 65.57 kg to 105.02 kg for males. Height for females was 150.6 cm to 180.5 cm and 166.2 cm to 191.2 cm for males. This distribution of heights and weights and how it was determined is described in more detail in appendix B and in tables D-1 and D-2 which give the height-weight categories used for males and females. Tables D-3 and D-4 give the subjects' anthropometric data.

Procedure:

Subjects were asked to wear shorts and T-shirts (or halters for females) for static anthropometric measurements. The subject was then screened by height and weight to determine if she/he fit into one of the needed height-weight categories. While this was being done the subjects name, age, and sex were recorded by another experimenter. If the subject fit one of the desired height-weight categories, the following static anthropometric measures were taken: stature, weight, sitting height, sitting eye height (slumped and erect), acromiale height (sitting--preferred side), biacromial diameter, bitrochanter breadth, buttock-knee length, buttock-popliteal length, sitting knee height, popliteal height, acromiale-radiale distance, radiale-stylion distance, stylion-knuckle length, stylion-fingertip length, stylion-thumbtip length, thumb length, grip length, C-7 height (sitting), L-1 height (sitting), thigh height (sitting) and stomach depth (sitting).

Following these measurements the subject was seated in the chair and restrained with lap and shoulder straps preparatory to the first reach protocol.

Table D-1. Height-Weight Stratified Sample
(Males Only)

Weight (kg) \ Height (cm)	164.0–172.4	172.4–175.9	175.9–179.1	179.1–182.8	182.8–192.8
85.0–102.9	0	1/2	1/2	1.5	2.5
80.0–85.0	1/2	1.0	1.0	1.0	1.5
75.6–80.0	1/2	1.0	2.0	1.0	1/2
71.0–75.6	1.5	1.0	1.0	1.0	1/2
56.7–71.0	2.5	1.5	1/2	1/2	0

Table D-2. Height-Weight Stratified Sample
(Female Only)

Weight (kg) \ Height (cm)	148.2–156.8	156.8–160.4	160.4–163.6	163.6–167.2	167.2–178.1
63.73–82.05	0	1/2	1/2	1.5	2 5
59.12–63.73	1/2	1.0	1.0	1.0	1.5
55.5–59.12	1/2	1.0	2.0	1.0	1/2
51.41–55.5	1.5	1.0	1.0	1.0	1/2
42.36–51.41	2.5	1.5	1/2	1/2	0

Table D-3. Male Anthropometric Data

Subject	Height	Weight (kg)	Sitting Height	Sitting Eye Ht. (Slumped)	Sitting Eye Ht. (Erect)	Sitting Acromiale Ht.	Biacromial Diameter	Bitrochantric Diameter	Buttock-Knee Length	Buttock-Popliteal Length	Knee Ht. (Sitting)	Popliteal Ht.	Acromiale-Radiale	Radiale-Stylion	Stylion-Grip Center	Stylion-Medial Digit	Stylion-Thumbtip	Thumb Length	Grip Length	C7 Ht. (Sitting)	L1 Ht. (Sitting)	Thigh Ht.	Abdominal Depth	Age	Ethnic Class
1)DRR	191.2	092.95	97.4	80.5	84.3	59.5	43.9	33.0	64.8	55.4	57.8	47.9	37.6	27.9	6.75	21.4	14.6	7.1	38.2	68.7	—	—	—	19	CA
2)HHG	171.7	066.18	88.5	74.9	78.9	57.3	38.3	29.1	58.1	48.7	52.3	42.5	31.9	26.4	5.7	19.1	13.4	7.1	36.2	62.1	—	—	—	19	CA
3)CAH	168.3	065.57	85 9	74.1	76.1	55.6	41 1	30.7	58.1	48.4	51.6	42.7	33.6	25.5	8.0	18.5	14.1	6.6	34.9	60.0	—	—	—	25	CA
4)SG	168.7	086.82	83.2	69.7	73.4	53.4	41.0	33.7	62.1	53.6	53.0	43.9	35.6	27.4	8.1	19.5	14.4	6.8	37.4	61.0	22.8	56.5	—	42	BL
5)CON	176.7	070.23	94.7	78.4	83.7	59.4	40.1	27.4	54.9	50.5	51.4	43.0	33.2	26.6	7.3	18.5	13.3	7.2	36.0	67.1	—	—	—	19	CA
6)SFM	166.4	063.86	82 9	69 5	71.4	58.2	35.9	28.7	58.4	50.0	52.9	43.6	33.2	28.9	6.9	18.3	13.0	6.8	36.6	60.0	13.3	55.1	—	23	CA
7)AWM	174.6	065.45	90.7	78.9	82.2	60.4	43.1	30.7	59.7	53.0	53.4	44.2	35.1	26.1	8.8	19.6	13.3	6.2	35.0	67.0	20.2	55.1	—	20	CA
8)RJM	183.6	091.22	93.5	79 1	81.9	61.9	41.8	33.4	64.4	54.8	56.3	46.8	35.8	29.6	8.6	19.4	13.3	6.8	38.9	67.4	18.8	59.2	—	18	CA
9)HSM	179.2	075.60	93.7	79.9	82.2	65.8	38.2	34.1	61.2	52.8	53.2	44.3	35.4	27.7	7.3	19.0	13.1	6.9	36.6	67.5	18.6	57.7	—	19	CA
10)WCB	185.7	106.02	96.9	83.6	84.9	65.1	39.8	37.3	65.9	56.1	56.8	46.3	36.6	29.6	5.9	19.1	13.8	7.2	36.9	70.2	18.3	59.3	—	21	CA
11)PG	181.3	084.20	94.0	77.0	80.6	61.4	42.9	32.0	62.4	53.6	55.2	48.0	35.9	26.7	6.8	18.8	13.1	7.2	35.1	68.7	18.0	59.6	—	19	CA
12)THX	178.0	070.80	92.8	80.2	83.7	60.3	40.4	31.1	59.9	51.3	54.7	45.6	33.9	26.7	7.7	20.3	14.5	7.0	36.0	65.1	18.1	56.4	21.9	21	CA
13)KS	180.7	069.89	91.9	79.8	80.9	61.3	35.6	30.0	61.2	52.0	56.3	48.2	34.5	27.8	8.2	20.3	12.2	5.7	38.0	65.8	15.7	57.2	21.0	21	CA
14)BRX	183.8	084.20	97.0	84.2	85.4	66.4	40.6	33.9	63.6	54.0	55.4	45.3	36.2	28.6	7.8	20.2	13.3	6.3	38.5	70.2	16.4	58.1	26.1	31	CA
15)RGX	174.0	069.55	90.4	77.6	79 2	59.7	39.9	31.8	60.0	51.5	54.0	45.1	35.7	27.7	6.6	18.4	12.2	7.3	36.3	63.5	20.1	57.5	22.3	19	CH
16)DHX	179.0	072.04	90.1	78.5	80.9	61.4	38.5	29.8	60.6	52.4	56.3	46.9	35.5	27.6	7.9	20.8	13.6	6.4	37.3	64.5	15.0	58.7	22.1	22	CA
17)DPK	183.1	080.68	92.3	77.4	80.9	59.5	42.9	32.1	61.4	52.4	54.8	46.5	36.3	28.5	7.5	19.5	12.5	6.2	37.4	66.5	15.7	58.1	24.4	23	CA
18)DJD	176.3	075.91	94.0	81.7	83.4	62.2	37.8	31.1	59.8	51.0	51.7	42.3	34.2	26.1	6.6	19.0	13.5	6.8	35.2	65.1	17.7	54.9	26.0	25	CA
19)DAD	178.5	075.91	92.4	77.9	81.1	58.4	40.8	32.7	62.5	53.4	55.0	45.6	34.8	27.9	7.0	19.8	12.8	6.5	37.7	67.7	16.6	57.2	23.6	22	CA
20)DJR	166.2	071.25	86.1	72.2	73.5	56.9	36.4	29.3	56.0	46.2	52.1	42.0	32.9	25.3	6.8	18.7	12.4	6.4	33.6	60.9	14.9	53.5	23.0	21	CA
21)JWS	183.5	070.34	94.5	79.8	82.1	62.4	38.8	30.5	61.0	51.6	55.0	45.6	36.4	29.2	7.2	20.3	13.4	6.5	37.0	65.0	15.6	57.1	21.1	19	CA
22)XJP	179.0	074.66	92.6	81.3	82.4	60.9	40.6	31.5	59.8	51.4	55.8	45.5	34.4	28.6	6.8	19.2	13.1	7.1	36.5	65.7	16.7	57.2	21.7	20	CA
23)CGH	176.5	075.91	88.4	75.3	77.8	58.5	38.0	30.7	60.7	51.2	53.0	42.5	32.9	25.0	6.7	19.8	13.8	6.9	33.9	61.3	11.0	55.4	25.1	39	CA
24)MOC	174.8	069.43	88.5	75.1	79.7	62.0	40.5	29.3	60.0	51.7	54.3	45.4	35.1	27.3	8.1	19.5	12.9	6.0	35.9	64.3	13.3	56.1	19.4	23	CA
25)SBX	173.1	090.23	90.1	76.2	78.3	56.3	41.6	32 1	61.4	52.3	50.0	40.0	35.2	26.1	7.1	18.6	11.7	5.8	35.2	64.3	13.3	55.4	29.9	23	CA

*NOTE: All measurements are in cm unless otherwise noted.

Table D-4. Female Anthropometric Data

Subject	Height	Weight (kg)	Sitting Height	Sitting Eye Ht. (Slumped)	Sitting Eye Ht. (Erect)	Sitting Acromiale Ht.	Biacromial Diameter	Bitrochantric Diameter	Buttock-Knee Length	Buttock-Popliteal Length	Knee Ht. (Sitting)	Popliteal Ht.	Acromiale-Radiale	Radiale-Stylion	Stylion-Grip Center	Stylion-Medial Digit	Stylion-Thumbtip	Thumb Length	Grip Length	C7 Ht. (Sitting)	L1 Ht. (Sitting)	Thigh Ht.	Abdominal Depth	Age	Ethnic Class
1)SJN	163.9	61.25	85.3	72.6	73.8	54.7	37.8	30.6	57.9	50.4	50.6	41.1	30.7	24.3	5.2	16.9	12.6	6.5	30.0	57.4	—	—	—	18	CA
2)TKS	162.5	60.57	85.1	73.8	74.2	55.1	35.2	30.8	57.7	48.7	48.5	40.1	32.4	24.8	6.7	17.1	11.8	5.9	32.3	60.4	—	—	—	16	CA
3)JSB	163.7	71.48	91.4	73.9	81.6	62.4	37.6	32.0	56.9	47.9	47.5	39.6	32.6	22.4	7.0	17.8	12.9	5.9	32.1	67.3	27.2	51.2	—	20	CA
4)SRM	153.6	46.02	82.8	71.2	72.1	53.7	34.6	28.2	52.0	44.0	45.2	37.8	30.3	24.0	6.1	16.3	11.4	5.5	30.1	58.6	20.1	48.3	—	19	CA
5)MVM	170.0	54.43	88.6	77.5	78.6	56.5	35.8	31.6	59.3	51.9	51.2	42.4	33.4	26.0	6.6	18.5	12.8	6.8	33.7	61.8	19.1	52.8	—	19	CA
6)DCA	160.6	54.20	84.3	66.9	83.8	55.8	33.5	31.4	56.8	48.8	48.2	39.9	29.9	25.1	5.4	17.3	12.1	6.0	31.6	59.4	21.3	51.8	—	19	CA
7)TCX	166.1	66.25	85.6	74.2	76.1	53.2	38.0	31.4	60.5	53.6	51.5	43.0	33.3	25.6	6.3	17.8	12.7	6.2	34.0	61.7	18.0	53.4	21.8	18	CA
8)JBX	160.1	58.98	84.[illegible]	71.0	72.0	53.7	36.8	31.7	58.0	47.8	47.9	39.3	31.1	22.5	6.5	17.2	11.4	5.9	30.6	59.8	15.4	51.4	21.3	18	CA
9)KLX	163.3	56.82	87.7	77.4	77.5	57.8	36.1	32.3	56.0	48.4	37.7	39.9	31.6	23.4	6.4	17.4	11.2	6.0	31.2	63.3	18.2	50.3	19.1	19	CA
10)EMX	175.4	60.11	90.0	79.1	81.1	62.5	37.1	30.0	59.6	51.9	53.3	44.5	33.0	24.6	7.7	19.1	13.2	5.4	34.6	65.1	19.1	55.4	19.4	20	CA
11)DLE	166.0	49.65	83.8	74.6	74.6	54.9	34.8	29.3	58.9	51.0	50.9	42.4	30.5	25.0	5.9	17.8	12.0	6.1	32.2	57.1	16.9	54.1	16.5	20	CA
12)LLR	160.0	47.77	83.4	70.8	73.0	56.8	31.4	29.5	56.0	48.4	49.0	40.5	31.1	23.7	6.9	17.4	11.1	6.1	31.6	59.4	16.8	51.3	16.6	21	CA
13)CBD	167.0	57.73	87.4	76.8	77.6	57.7	36.2	32.1	57.3	48.2	51.2	42.1	32.1	24.5	6.4	17.5	11.6	5.9	32.0	63.2	17.1	53.5	19.1	18	CA
14)DXG	170.0	62.23	87.1	76.7	77.1	55.5	35.9	33.4	61.1	52.5	51.8	42.6	34.0	24.8	6.7	17.6	11.8	6.0	33.2	63.5	16.1	53.3	21.5	20	CA
15)SLB	177.7	58.75	87.2	73.1	76.3	57.6	38.5	30.3	63.3	55.9	55.0	45.5	36.5	25.7	6.4	18.0	12.4	6.0	34.7	62.1	14.6	55.7	19.2	18	CA
16)XRA	158.9	52.27	84.8	74.8	76.4	56.1	34.4	29.7	54.5	46.4	48.1	40.0	30.7	23.1	6.7	16.8	11.4	5.5	31.0	59.9	13.8	51.3	18.3	18	CA
17)CMC	163.5	56.82	84.5	72.6	73.[illegible]	55.0	35.2	31.5	56.9	48.9	49.4	42.1	31.5	23.8	6.8	17.6	11.9	6.1	32.3	59.2	17.9	53.3	19.4	18	CA
18)CPX	157.8	56.82	84.8	71.7	73.5	54.4	36.9	32.0	54.2	44.8	47.3	39.6	30.4	24.0	7.3	16.4	11.7	5.6	42.8	60.4	17.1	52.6	20.4	18	CA
19)MAS	150.6	49.54	80.4	68.4	70.4	50.3	33.4	29.6	53.2	44.1	43.3	36.2	29.5	22.4	5.4	15.9	11.1	5.3	27.7	54.3	19.2	48.7	17.3	22	CA
20)LLN	158.0	45.45	83.2	71.8	72.2	55.3	34.5	29.0	53.2	45.1	47.3	39.7	29.3	23.1	6.9	17.6	12.0	5.9	32.0	59.9	15.9	49.2	18.6	18	CA
21)WES	158.1	58.41	84.6	71.5	73.8	51.7	36.2	31.8	54.2	46.1	47.7	39.6	29.2	22.3	6.0	16.7	11.3	5.8	29.6	58.9	14.5	50.8	19.0	19	CA
22)JRB	180.5	66.14	91.4	78.3	78.7	59.6	36.7	31.5	64.6	56.7	53.9	45.5	35.4	26.0	7.2	19.4	13.7	6.2	33.7	63.9	16.8	57.4	21.4	19	CA
23)MEG	163.7	55.00	87.2	77.4	79.3	55.1	38.9	29.2	53.5	45.9	42.1	38.6	30.7	22.9	7.6	17.5	12.3	5.8	31.7	61.7	15.4	50.3	18.6	19	CA
24)SLL	159.9	52.50	83.9	71.6	72.5	53.4	36.0	30.7	55.4	47.9	47.8	39.8	29.7	24.0	6.7	17.4	12.1	5.8	32.2	60.0	15.4	51.0	18.3	20	CA

*NOTE: All measurements are in cm unless otherwise noted.

One hundred and twenty reach points were taken with the subject holding the grip handle of the ARA. Experimenter 1 (E1) supported the subject's arm on each reach and positioned the angle of reach in the vertical plane. Experimenter 2 (E2) sighted and corrected the reach azimuth angle in the horizontal plane using the plumb line suspended from the ceiling. When the subject's arm was in the proper position, E2 pressed a switch signaling the computer to sample the voltages currently registering in the potentiometers, one for vertical angle and one for azimuth angle, and the third for the radius angle.

Reaches were obtained in this manner for azimuth angles from 120^{o} to the subject's right of vertical midline to 45^{o} to the left of the subject's midline in 15^{o} increments.

Following data collection on the first protocol (restrained condition) the subject was allowed 5 to 10 minutes of rest before the second protocol (unrestrained condition).

After the rest period the subject was seated and restrained with a lap belt only. The data collection procedures for the second protocol were identical to the ones used for the first protocol. At the conclusion of the second data collection protocol data points were stored by the computer on magnetic tape for later analysis. The subject was given praticipation credit and released.

Results and Discussion

The summary statistics (x and y coordinates for 5th percentile, mean, and 95th percentile) for reach envelopes (male and female; restrained and unrestrained) are presented in tables 5, 6, 7, and 8 in appendix C. Graphic plots of the reach envelopes for the 40-cm, 60-cm, and 90-cm altitudes are presented in figures 7 through 18, also in appendix C. Each figure has the 5th percentile, mean, and 95th percentile reaches plotted.

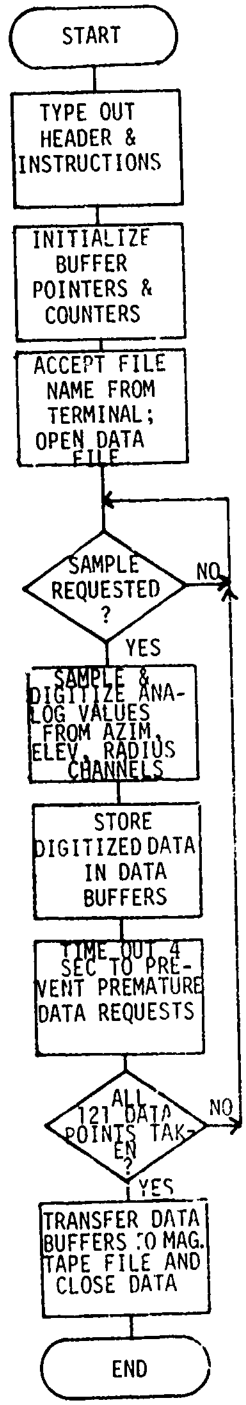
In general, the present reach envelope data appear to closely approximate the data reported in the literature (i.e., Kennedy, 1964). For purposes of comparison, the data from the 50-cm altitude for restrained males was chosen to be contrasted with Kennedy's 20-inch altitude data (see table 9 in appendix C).

The 50-cm altitude data collected at Texas Tech is within 5 inches in many cases when compared to the 20-inch altitude data from Kennedy (1964). This difference is primarily due to the type of reach used in the Tech study which was a grip center reach rather than grasp reach (thumb and fingers pinched together) used by Kennedy. Another variable which could have contributed to these differences are the populations used in these studies.

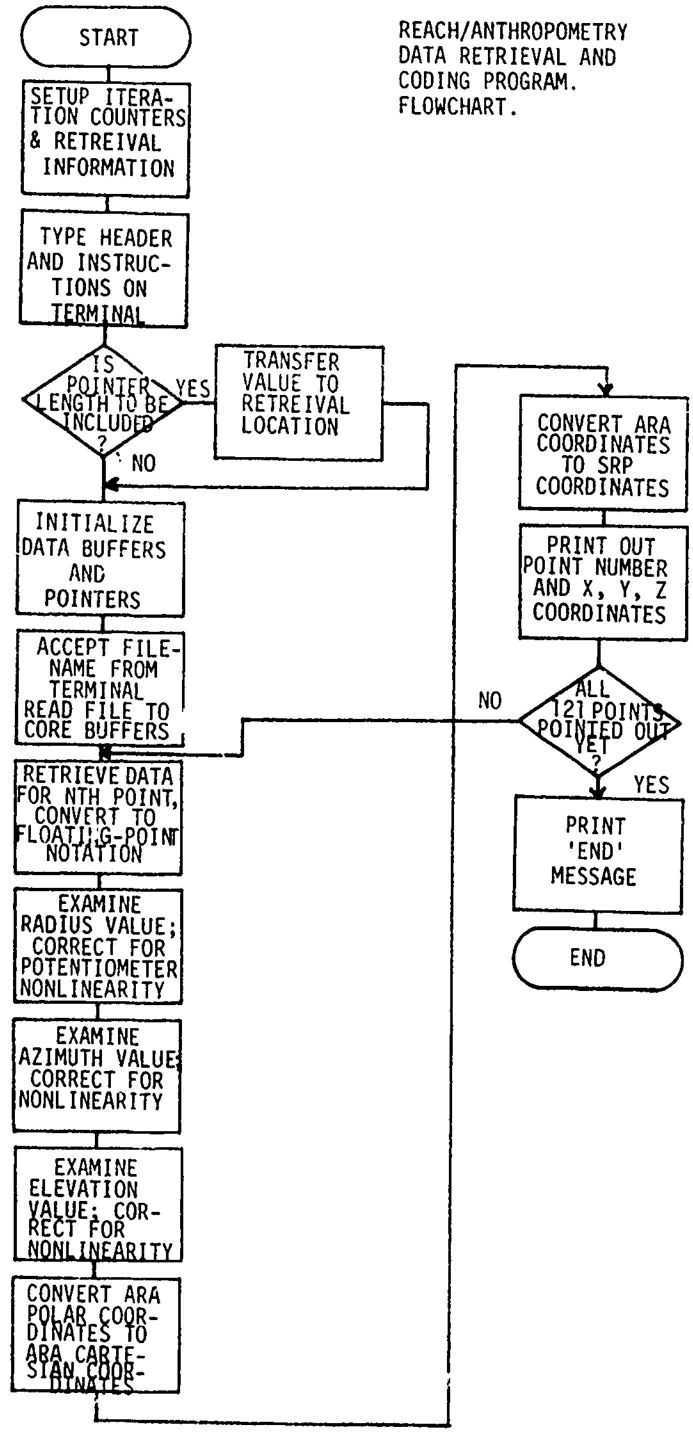
APPENDIX A

FLOWCHARTS AND LISTINGS OF SOFTWARE

REACH/ANTHROPOMETRY
DATA COLLECTION PGM.
FLOW CHART



REACH/ANTHROPOMETRY
DATA RETRIEVAL AND
CODING PROGRAM.
FLOWCHART.



APPENDIX B

PROCEDURE FOR DETERMINATION OF HEIGHT-WEIGHT
STRATIFIED SAMPLING PLANS

APPENDIX B

PROCEDURE FOR DETERMINATION OF HEIGHT-WEIGHT STRATIFIED SAMPLING PLANS

Before data collection was initiated, it was noted that height-weight sampling plans would be needed. A search for suitable male and female plans was initiated, but none was found in the on-hand literature. When the running of subjects had proceeded to about 15 percent, it was decided to develop a sampling plan.

Male height-weight correlations were found for the most recent tri-service data and found to lie between 0.45 and 0.55. The Clauser et al., (1972) study of Air Force women was found to have a correlation of 0.53; hence, a target correlation of 0.50 was selected. The approach used was to divide the ranges of both height and wieght into five equal proportions: (1) 0-20th percentile; (2) 20th-40th percentile; (3) 40th-60th percentile; (4) 60th-80th percentile; and (5) 80th-100th percentile. This resulted in a five-row by five-column (25-cell) array that would have contained exactly one entry per cell if the correlation had been zero. Appropriate numbers per cell for $r = 0.50$ were then determined using 400 to 1000 sample runs of a Monte Carlo procedure described by Bittner (1974; 1975). The result is shown in tables 1 and 2 where cells were rounded to half subjects. This was done to allow the experimenters some flexibility in assigning cells. Applied to male and female populations, this resulted in the plans given in tables 1 and 2. Here it should be noted that extreme cut offs were not set at the (impossible) 0th-and 100th-percentile values, but rather were set at the 0.5th and 99.5th percentiles as determined from Gifford et al., (1965) for males and Clauser et al., (1972) for females.

The effectiveness of these plans can be seen by comparing the results of this study with those given in Gifford et al., and Clauser et al. Compared with other studies our errors in both means and standard deviations appear to be of equal or smaller magnitude. Thus the effectiveness of the plan appears to be good and could be recommended for other similar studies.

APPENDIX C

SUMMARY STATISTICS

AND

GRAPHIC PLOTS OF REACH ENVELOPES

Table 5. Summary Statistics for Restrained Males (cm)

AZIMUTH ANGLE 120. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	24.80	0.00	24.80	24.80	45.04	0.00	45.04	45.04
10.	28.73	2.31	24.93	32.54	51.51	3.26	46.14	56.87
20.	33.38	2.15	29.84	36.91	59.74	2.46	55.70	63.78
30.	36.05	1.81	33.07	39.03	64.55	2.22	60.90	68.19
40.	38.08	1.69	35.31	40.85	67.63	2.23	63.97	71.30
50.	38.85	1.62	36.19	41.51	68.72	2.57	64.49	72.94
60.	39.25	1.71	36.43	42.07	69.27	3.02	64.29	74.24
70.	38.27	1.77	35.36	41.17	68.06	3.25	62.72	73.41
80.	36.80	2.03	33.45	40.14	66.25	3.68	60.20	72.31
90.	34.49	2.40	30.54	38.45	62.40	3.97	55.87	68.92
100.	30.91	3.23	25.60	36.23	55.97	5.11	47.56	64.37
110.	25.69	3.82	19.41	31.97	46.36	6.90	35.00	57.72
120.	18.27	4.27	11.24	25.30	34.61	8.13	21.24	47.98
130.	15.82	0.00	15.82	15.82	31.21	0.00	31.21	31.21
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Continued

AZIMUTH ANGLE 105. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	12.38	1.72	9.56	15.21	49.88	4.47	42.52	57.23
10.	13.94	1.26	11.87	16.01	59.00	3.83	52.69	65.30
20.	16.25	1.10	14.44	18.07	68.07	3.05	63.05	73.09
30.	17.67	1.02	16.00	19.34	73.33	2.87	68.60	78.06
40.	18.80	1.09	16.99	20.60	76.74	2.63	72.42	81.07
50.	18.95	1.01	17.29	20.60	78.21	2.61	73.91	82.51
60.	18.86	1.07	17.10	20.62	78.93	3.04	73.93	83.92
70.	18.26	1.29	16.14	20.38	76.99	3.01	72.03	81.95
80.	17.54	1.65	14.82	20.26	74.47	3.24	69.15	79.79
90.	16.34	1.59	13.72	18.95	70.01	3.67	63.97	76.04
100.	14.49	1.78	11.55	17.42	63.52	4.57	55.99	71.04
110.	11.81	2.36	7.93	15.69	52.87	7.19	41.03	64.70
120.	9.00	2.20	5.38	12.62	40.23	8.42	26.43	54.13
130.	6.17	2.23	2.50	9.84	35.24	3.18	30.01	40.47
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Continued

AZIMUTH ANGLE 90. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.98	0.71	-0.19	2.15	50.81	4.21	43.89	57.73
10.	1.24	0.61	0.25	2.24	60.22	3.96	53.71	66.74
20.	1.39	0.76	0.15	2.64	69.86	3.24	64.52	75.19
30.	1.59	0.71	0.42	2.76	75.50	3.01	70.54	80.46
40.	1.62	0.64	0.56	2.68	79.13	2.85	74.44	83.83
50.	1.78	0.74	0.56	2.99	80.63	3.05	75.60	85.65
60.	1.97	0.64	0.92	3.03	80.99	3.47	75.28	86.69
70.	2.00	0.58	1.05	2.95	79.24	3.81	72.98	85.49
80.	2.01	0.74	0.80	3.23	76.22	3.92	69.77	82.67
90.	1.94	0.74	0.72	3.15	71.81	3.88	65.43	78.20
100.	2.08	0.84	0.70	3.46	65.02	4.86	57.02	73.02
110.	2.22	1.02	0.54	3.90	53.99	7.00	42.47	65.51
120.	2.64	0.81	1.32	3.97	40.68	8.73	26.32	55.03
130.	3.52	0.00	3.52	3.52	36.70	0.00	36.70	36.70
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Continued

AZIMUTH ANGLE 75. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	14.21	1.11	12.38	16.04	49.22	3.82	42.93	55.52
10.	16.73	1.25	14.68	18.78	57.07	4.06	50.39	63.75
20.	19.29	1.09	17.50	21.08	66.70	3.19	61.44	71.95
30.	20.80	0.92	19.29	22.31	72.25	3.00	67.31	77.19
40.	21.82	0.97	20.23	23.41	75.66	2.70	71.21	80.10
50.	22.19	0.89	20.73	23.66	76.99	2.69	72.57	81.42
60.	22.27	1.00	20.63	23.91	77.37	2.94	72.53	82.21
70.	21.91	0.95	20.34	23.48	75.86	3.15	70.68	81.05
80.	21.28	0.91	19.77	22.78	73.18	3.33	67.71	78.65
90.	20.15	0.96	18.57	21.74	68.84	3.64	62.86	74.83
100.	18.39	1.39	16.10	20.67	62.10	4.18	55.23	68.97
110.	16.01	1.87	12.93	19.10	50.26	6.88	38.93	61.58
120.	13.24	1.86	10.16	16.30	38.59	7.17	26.79	50.40
130.	11.12	0.00	11.12	11.12	31.96	0.00	31.96	31.96
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Continued

AZIMUTH ANGLE 60. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	26.08	0.81	24.75	27.42	43.15	1.14	41.28	45.02
10.	30.79	1.80	27.83	33.74	49.34	3.38	43.78	54.90
20.	35.72	1.66	32.98	38.45	57.65	3.15	52.47	62.83
30.	38.55	1.57	35.96	41.13	62.75	2.67	58.35	67.15
40.	40.37	1.50	37.91	42.83	65.70	2.61	61.40	69.99
50.	41.19	1.40	38.90	43.49	66.96	2.60	62.68	71.24
60.	41.44	1.38	39.17	43.71	67.39	2.61	63.10	71.69
70.	40.65	1.52	38.16	43.14	66.05	2.64	61.71	70.38
80.	39.24	1.80	36.28	42.21	63.52	2.85	58.83	68.21
90.	36.94	2.11	33.46	40.41	59.15	3.35	53.63	64.66
100.	33.40	2.76	28.86	37.95	52.29	4.[illegible]9	45.23	59.36
110.	27.49	3.77	21.29	33.70	41.64	6.68	30.65	52.63
120.	22.10	3.89	15.71	28.50	33.69	6.40	23.17	44.22
130.	19.23	0.00	19.23	19.23	27.90	0.00	27.90	27.90
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Continued

AZIMUTH ANGLE 45. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	30.63	1.62	27.97	33.30	32.49	0.95	30.92	34.06
10.	39.25	2.70	34.80	43.69	38.35	3.22	33.05	43.64
20.	46.19	2.88	41.46	50.92	44.98	3.17	39.77	50.20
30.	50.53	2.63	46.19	54.86	49.26	2.58	45.02	53.51
40.	53.00	2.44	48.98	57.02	51.77	2.40	47.82	55.73
50.	54.02	2.36	50.14	57.90	52.88	2.28	49.13	56.63
60.	54.14	2.26	50.43	57.85	53.03	2.32	49.21	56.86
70.	53.04	2.27	49.31	56.77	51.74	2.48	47.66	55.83
80.	51.23	2.45	47.20	55.27	49.57	2.75	45.04	54.11
90.	48.23	2.86	43.53	52.93	46.15	3.19	40.89	51.40
100.	43.29	3.39	37.71	48.87	41.26	3.60	35.33	47.19
110.	35.27	4.43	27.98	42.56	33.02	4.64	25.38	40.65
120.	26.93	6.36	16.47	37.40	25.52	5.51	16.45	34.59
130.	24.35	0.00	24.35	24.35	22.05	0.00	22.05	22.05
140.	0.00	0.00	0.00	0.00	0.00	0.00	9.00	0.00

Table 5. Continued

AZIMUTH ANGLE 30. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	44.67	3.19	39.43	49.92	26.52	2.55	22.34	30.71
20.	52.13	3.13	46.98	57.28	31.05	2.46	27.00	35.10
30.	56.75	2.67	52.36	61.13	33.53	2.05	30.16	36.90
40.	59.66	2.70	55.22	64.11	34.89	1.97	31.65	38.12
50.	60.97	2.67	56.58	65.36	35.54	1.73	32.69	38.39
60.	61.32	2.69	56.89	65.76	35.80	1.84	32.77	38.83
70.	60.22	2.87	55.49	64.94	35.11	2.10	31.66	38.55
80.	58.08	3.00	53.15	63.01	33.67	2.21	30.03	37.31
90.	54.38	3.46	48.68	60.07	31.09	2.51	26.97	35.21
100.	48.24	4.30	41.18	55.31	27.51	3.15	22.33	32.56
110.	38.34	5.76	28.87	47.82	21.87	3.91	15.44	28.30
120.	33.18	6.30	22.83	43.54	19.47	2.71	15.02	23.93
130.	29.53	0.00	29.53	29.53	16.06	0.00	16.06	16.06
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Continued

AZIMUTH ANGLE 15. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	45.91	3.80	39.66	52.16	13.60	1.45	11.22	15.98
20.	53.25	3.52	47.46	59.04	15.02	1.97	11.78	18.27
30.	57.99	3.04	52.98	63.00	16.22	1.95	13.01	19.43
40.	61.07	3.49	55.33	66.80	17.14	1.49	14.69	19.60
50.	62.15	3.24	56.82	67.49	17.35	1.25	15.29	19.41
60.	62.76	3.19	57.50	68.01	17.46	1.34	15.26	19.66
70.	61.77	3.33	56.30	67.24	17.10	1.61	14.46	19.75
80.	59.70	3.47	53.99	65.41	16.49	1.81	13.52	19.46
90.	55.86	3.87	49.48	62.23	15.15	2.02	11.83	18.47
100.	48.68	5.96	38.88	58.48	13.16	2.12	9.68	16.65
110.	39.54	5.91	29.83	49.26	10.41	1.99	7.14	13.68
120.	32.50	13.65	10.04	54.96	7.82	4.32	0.71	14.93
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Continued

AZIMUTH ANGLE 0. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	43.87	4.61	36.29	51.45	1.09	0.28	0.64	1.55
20.	51.75	3.84	45.44	58.06	1.08	0.32	0.57	1.58
30.	56.37	3.37	50.82	61.92	0.95	0.28	0.48	1.42
40.	58.94	3.42	53.32	64.57	0.96	0.29	0.49	1.43
50.	59.69	3.50	53.93	65.46	0.96	0.26	0.53	1.38
60.	59.59	3.92	53.14	66.04	1.00	0.32	0.48	1.52
70.	58.15	4.40	50.92	65.38	0.99	0.35	0.41	1.56
80.	55.59	4.87	47.58	63.60	1.07	0.39	0.43	1.71
90.	51.54	5.19	43.00	60.08	1.11	0.35	0.54	1.68
100.	44.85	6.88	33.53	56.18	1.09	0.40	0.44	1.74
110.	34.49	7.24	22.58	46.40	1.36	0.61	0.36	2.37
120.	16.40	12.12	-3.54	36.34	1.38	0.39	0.73	2.03
130.	20.26	0.00	20.26	20.26	1.31	0.00	1.31	1.31
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Continued

AZIMUTH ANGLE -15. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	44.93	3.86	38.59	51.28	11.87	3.21	6.59	17.15
30.	47.93	3.39	42.35	53.50	12.24	1.77	9.33	15.15
40.	48.36	5.31	39.62	57.09	12.77	2.06	9.38	16.15
50.	49.61	6.10	39.58	59.65	13.04	2.25	9.33	16.75
60.	49.82	6.92	38.44	61.21	12.97	2.53	8.81	17.13
70.	48.42	8.09	35.11	61.73	12.41	2.64	8.08	16.75
80.	46.66	7.97	33.54	59.77	11.58	2.46	7.53	15.62
90.	43.47	8.22	29.95	56.99	10.58	2.34	6.72	14.43
100.	38.66	7.07	27.03	50.30	9.23	2.36	5.35	13.12
110.	29.67	6.87	18.38	40.97	6.88	2.43	2.88	10.88
120.	29.45	6.23	19.21	39.69	7.29	1.44	4.93	9.65
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Continued

AZIMUTH ANGLE -30. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	37.54	0.00	37.54	37.54	23.27	0.00	23.27	23.27
30.	36.55	4.51	29.12	43.97	20.05	3.18	14.82	25.28
40.	36.98	5.93	27.23	46.73	20.62	4.12	13.84	27.40
50.	37.49	6.88	26.18	48.80	21.24	4.41	13.99	28.50
60.	37.27	7.75	24.53	50.02	21.35	4.78	13.49	29.20
70.	35.89	7.66	23.29	48.50	20.29	4.85	12.31	28.26
80.	34.37	7.79	21.56	47.19	18.75	5.20	10.20	27.30
90.	31.83	7.71	19.14	44.52	16.56	5.56	7.42	25.70
100.	28.04	6.88	16.73	39.36	14.26	5.01	6.01	22.50
110.	22.39	6.29	12.04	32.74	11.50	4.01	4.89	18.10
120.	17.40	9.23	2.21	32.59	8.16	4.61	0.58	15.75
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5. Concluded

AZIMUTH ANGLE -45. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	24.61	1.77	21.70	27.52	24.07	2.18	20.48	27.66
30.	25.39	4.18	18.52	32.25	23.24	3.70	17.15	29.34
40.	25.70	4.07	19.01	32.39	23.74	4.24	16.77	30.71
50.	25.34	5.81	15.78	34.91	23.46	6.00	13.58	33.33
60.	24.68	6.39	14.16	35.20	22.75	6.58	11.94	33.57
70.	24.44	6.25	14.15	34.72	22.22	6.47	11.57	32.86
80.	23.56	5.76	14.08	33.04	20.55	6.51	9.84	31.25
90.	21.93	5.56	12.79	31.07	17.93	6.87	6.62	29.24
100.	19.26	6.27	8.94	29.58	15.16	6.51	4.45	25.87
110.	16.02	5.10	7.63	24.41	13.01	4.82	5.08	20.94
120.	10.53	3.67	4.49	16.58	9.17	4.13	2.38	15.97
130.	4.44	0.00	4.44	4.44	2.35	0.00	2.35	2.35
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Summary Statistics for Unrestrained Males (cm)

AZIMUTH ANGLE 120. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	25.42	1.38	23.16	27.69	45.11	4.26	38.09	52.12
10.	29.11	2.93	24.28	33.93	52.21	4.34	45.07	59.36
20.	33.49	2.83	28.83	38.14	59.17	3.79	52.93	65.41
30.	35.95	2.73	31.45	40.44	63.42	3.56	57.57	69.28
40.	37.65	2.77	33.09	42.21	66.49	3.30	61.07	71.91
50.	38.27	2.56	34.06	42.47	67.59	3.17	62.38	72.79
60.	38.62	2.50	34.50	42.73	68.15	3.30	62.73	73.57
70.	37.89	2.67	33.50	42.27	66.82	3.58	60.93	72.72
80.	36.90	2.93	32.09	41.72	64.95	4.06	58.27	71.63
90.	34.84	3.05	29.83	39.85	61.38	4.51	53.95	68.80
100.	31.80	3.44	26.15	37.45	56.46	4.96	48.31	64.62
110.	27.54	4.22	20.60	34.49	48.90	6.22	38.67	59.13
120.	21.56	5.07	13.21	29.91	38.24	7.59	25.75	50.73
130.	15.33	3.66	9.31	21.36	27.64	6.71	16.61	38.68
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Continued

AZIMUTH ANGLE 105. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	11.47	3.01	6.52	16.41	50.31	3.24	44.97	55.64
10.	13.90	2.71	9.45	18.36	59.14	5.01	50.90	67.37
20.	16.15	1.76	13.27	19.04	67.40	4.53	59.94	74.85
30.	16.79	3.79	10.56	23.03	72.14	4.46	64.81	79.47
40.	18.20	1.83	15.18	21.21	75.56	4.56	68.05	83.06
50.	18.43	1.90	15.31	21.55	76.54	4.64	68.92	84.17
60.	18.56	2.01	15.26	21.87	76.93	4.61	69.34	84.51
70.	18.13	1.81	15.15	21.10	75.52	4.88	67.50	83.54
80.	17.45	1.67	14.70	20.19	73.31	4.88	65.28	81.33
90.	16.47	1.79	13.52	19.42	69.41	5.51	60.34	78.48
100.	14.95	1.92	11.78	18.11	63.66	5.98	53.82	73.49
110.	12.58	2.34	8.73	16.42	55.10	7.52	42.73	67.47
120.	9.39	3.12	4.27	14.52	41.75	9.24	26.55	56.96
130.	6.14	1.94	2.95	9.34	32.17	6.75	21.06	43.27
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Continued

AZIMUTH ANGLE 90. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	2.34	1.12	0.50	4.18	53.10	2.90	48.34	57.87
10.	1.76	0.84	0.38	3.15	63.53	7.78	50.72	76.33
20.	1.80	0.72	0.61	2.99	71.50	7.16	59.72	83.28
30.	1.83	0.69	0.70	2.95	76.36	6.98	64.88	87.85
40.	1.85	0.75	0.62	3.09	79.82	7.06	68.20	91.43
50.	1.98	0.61	0.97	2.98	80.46	6.82	69.25	91.68
60.	2.08	0.68	0.96	3.21	80.70	6.84	69.44	91.96
70.	2.12	0.68	0.99	3.24	79.16	6.92	67.77	90.54
80.	2.05	0.71	0.88	3.22	76.80	6.99	65.29	88.31
90.	2.06	0.73	0.85	3.26	72.73	7.30	60.72	84.75
100.	2.18	0.62	1.16	3.20	66.36	7.61	53.84	78.89
110.	2.40	0.88	0.95	3.84	56.71	8.51	42.72	70.71
120.	2.44	1.02	0.76	4.12	43.29	9.88	27.04	59.54
130.	2.30	1.52	-0.20	4.80	32.70	8.04	19.47	45.93
140.	3.99	0.00	3.99	3.99	21.97	0.00	21.97	21.97

Table 6. Continued

AZIMUTH ANGLE 75. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	15.27	1.79	12.32	18.22	52.74	5.28	44.05	61.42
10.	17.68	2.05	14.30	21.06	61.35	7.93	48.31	74.39
20.	19.84	1.91	16.70	22.98	69.50	7.15	57.74	81.27
30.	21.37	1.66	18.65	24.10	74.04	6.74	62.95	85.12
40.	22.41	1.69	19.63	25.19	77.11	7.02	65.56	88.65
50.	22.66	1.64	19.95	25.36	78.00	6.75	66.89	89.11
60.	22.72	1.72	19.88	25.56	78.45	6.77	67.32	89.59
70.	22.47	1.69	19.68	25.26	77.10	6.84	65.84	88.35
80.	21.96	1.77	19.05	24.87	74.70	6.80	63.51	85.90
90.	20.89	2.07	17.48	24.30	70.50	7.07	58.88	82.12
100.	19.29	2.15	15.76	22.83	64.15	7.38	52.00	76.29
110.	16.92	2.33	13.09	20.75	55.01	8.49	41.05	68.97
120.	14.27	2.64	9.92	18.62	43.23	9.53	27.56	58.91
130.	12.12	2.64	7.77	16.47	33.93	8.43	20.06	47.80
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Continued

AZIMUTH ANGLE 60. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	29.76	5.47	20.77	38.76	49.10	10.81	31.32	66.87
10.	33.93	4.11	27.16	40.70	55.81	7.98	42.68	68.93
20.	38.13	3.71	32.04	44.23	62.84	7.11	51.14	74.54
30.	40.55	3.47	34.85	46.25	66.53	6.73	55.46	77.60
40.	42.35	3.48	36.62	48.08	69.07	6.77	57.94	80.20
50.	43.01	3.36	37.49	48.53	69.83	6.39	59.32	80.34
60.	43.24	3.43	37.60	48.88	69.97	6.29	59.63	80.32
70.	42.52	3.50	36.76	48.29	68.57	6.25	58.30	78.84
80.	41.13	3.37	35.59	46.66	66.07	5.99	56.23	75.92
90.	39.12	3.33	33.64	44.59	62.19	6.06	52.22	72.16
100.	36.35	3.56	30.49	42.21	56.52	6.37	46.05	66.99
110.	31.59	4.25	24.60	38.56	48.25	7.57	35.79	60.70
120.	25.18	4.57	17.67	32.70	36.92	8.49	22.97	50.88
130.	18.68	2.96	13.82	23.54	28.13	5.98	18.30	37.96
140.	12.69	0.00	12.69	12.69	21.72	0.00	21.72	21.72

Table 6. Continued

AZIMUTH ANGLE 45. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	41.00	6.47	30.35	51.65	39.42	3.48	33.70	45.14
10.	47.07	7.52	34.70	59.44	46.03	6.70	35.00	57.06
20.	52.96	6.78	41.80	64.12	51.91	6.25	41.63	62.20
30.	56.25	6.38	45.76	66.74	55.01	6.26	44.72	65.30
40.	58.72	6.19	48.53	68.91	57.02	6.32	46.62	67.42
50.	59.60	5.87	49.95	69.26	57.43	6.01	47.55	67.31
60.	60.09	5.65	50.79	69.40	57.41	5.95	47.62	67.21
70.	59.03	5.70	49.66	68.41	56.13	5.68	46.78	65.48
80.	57.22	5.48	48.21	66.22	54.27	5.44	45.33	63.21
90.	54.57	5.54	45.46	63.69	51.11	5.48	42.09	60.13
100.	50.59	5.79	41.07	60.12	46.59	5.33	37.82	55.37
110.	44.10	6.30	33.73	54.47	39.80	5.71	30.42	49.19
120.	35.24	6.51	24.53	45.94	30.85	6.27	20.53	41.17
130.	28.66	6.29	18.32	39.00	25.56	5.64	16.29	34.84
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Continued

AZIMUTH ANGLE 30. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	48.64	3.85	42.30	54.98	29.07	4.62	21.46	36.67
10.	54.89	10.08	38.32	71.47	32.60	7.23	20.70	44.49
20.	62.19	8.71	47.87	76.51	36.82	6.62	25.94	47.71
30.	66.36	8.50	52.38	80.33	38.91	6.63	28.00	49.81
40.	70.12	9.06	55.22	85.02	40.49	6.37	30.02	50.96
50.	71.37	8.82	56.86	85.87	40.87	6.24	30.60	51.15
60.	71.99	8.68	57.70	86.28	40.93	6.20	30.73	51.13
70.	71.46	8.56	57.38	85.53	40.34	6.13	30.26	50.42
80.	69.89	8.14	56.49	83.28	39.17	6.12	29.11	49.23
90.	67.10	8.05	53.86	80.33	37.32	6.16	27.18	47.46
100.	61.71	7.88	48.75	74.67	34.15	6.00	24.27	44.03
110.	53.81	8.94	39.11	68.52	29.28	6.01	19.39	39.17
120.	42.05	9.94	25.69	58.40	22.29	6.29	11.95	32.64
130.	33.65	8.58	19.54	47.76	18.32	4.50	10.92	25.73
140.	27.58	0.00	27.58	27.58	13.80	0.00	13.80	13.80

Table 6. Continued

AZIMUTH ANGLE 15. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	56.49	5.13	48.05	64.93	13.61	6.25	3.34	23.88
10.	60.08	9.76	44.03	76.14	16.52	4.37	9.34	23.71
20.	67.34	7.98	54.21	80.48	18.37	4.71	10.62	26.13
30.	70.97	7.92	57.95	83.99	19.20	4.64	11.57	26.84
40.	73.56	8.72	59.21	87.91	19.34	4.65	11.69	26.99
50.	74.82	8.70	60.51	89.12	19.41	4.68	11.71	27.10
60.	75.80	8.88	61.20	90.40	19.54	4.69	11.83	27.25
70.	75.55	8.96	60.82	90.29	19.22	4.69	11.51	26.94
80.	74.22	8.83	59.69	88.75	18.64	4.76	10.81	26.46
90.	71.31	8.92	56.64	85.98	17.52	4.68	9.82	25.21
100.	65.84	8.71	51.52	80.16	15.72	4.36	8.55	22.89
110.	57.01	9.53	41.34	72.68	13.18	3.88	6.79	19.56
120.	46.84	7.77	34.05	59.62	10.65	3.30	5.21	16.08
130.	35.32	9.49	19.71	50.92	8.99	4.08	2.28	15.69
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Continued

AZIMUTH ANGLE 0. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	56.68	6.77	45.55	67.82	1.05	0.44	0.34	1.77
10.	57.84	12.75	36.86	78.83	0.97	0.23	0.59	1.35
20.	66.84	10.48	49.61	84.07	1.80	4.24	-5.18	8.78
30.	70.26	9.27	55.00	85.51	1.68	4.21	-5.24	8.60
40.	72.83	8.76	58.41	87.25	1.69	4.14	-5.11	8.50
50.	73.66	8.09	60.34	86.97	1.65	4.02	-4.96	8.27
60.	73.98	7.82	61.11	86.84	1.59	3.86	-4.76	7.94
70.	73.40	7.51	61.05	85.75	1.53	3.68	-4.53	7.59
80.	72.31	7.19	60.49	84.13	1.46	3.48	-4.26	7.18
90.	69.42	7.01	57.88	80.96	1.46	3.25	-3.88	6.80
100.	64.12	7.03	52.55	75.68	1.51	2.95	-3.34	6.36
110.	55.66	8.61	41.50	69.83	1.61	2.62	-2.70	5.93
120.	38.88	13.30	17.01	60.75	1.61	1.85	-1.43	4.66
130.	24.38	11.37	5.68	43.09	1.39	0.43	0.68	2.10
140.	7.96	0.00	7.96	7.96	2.12	0.00	2.12	2.12

Table 6. Continued

AZIMUTH ANGLE -15. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	48.56	0.04	48.49	48.63	13.58	1.11	11.75	15.41
20.	50.41	8.30	46.76	74.06	14.90	3.83	8.60	21.20
30.	60.99	7.39	50.83	75.16	16.26	3.06	11.23	21.29
40.	65.70	7.31	53.67	77.73	17.24	2.69	12.82	21.67
50.	67.17	7.19	55.34	79.00	17.50	2.96	12.63	22.38
60.	68.31	7.40	56.15	80.48	17.51	3.38	11.96	23.07
70.	68.35	7.47	56.07	80.63	17.14	3.80	10.89	23.40
80.	67.26	7.54	54.86	79.66	16.40	4.37	9.21	23.59
90.	64.92	7.45	52.66	77.17	15.51	4.11	8.74	22.27
100.	60.66	7.48	48.36	72.96	14.79	2.64	10.45	19.12
110.	52.17	8.86	37.59	66.74	13.48	3.38	7.92	19.03
120.	39.98	8.44	26.10	53.86	10.05	2.82	5.41	14.69
130.	29.66	8.12	16.30	43.02	7.86	2.50	3.74	11.98
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Continued

AZIMUTH ANGLE -30. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	61.09	0.00	61.09	61.09	34.32	0.00	34.32	34.32
20.	50.91	5.95	41.13	60.70	26.12	5.61	16.89	35.35
30.	50.70	5.91	40.98	60.43	26.41	7.39	14.25	38.56
40.	53.05	5.64	43.77	62.33	27.05	9.84	10.86	43.23
50.	54.26	5.35	45.46	63.06	27.16	9.92	10.84	43.48
60.	54.91	5.17	46.40	63.41	26.39	10.95	8.37	44.41
70.	55.00	5.09	46.62	63.38	26.18	10.43	9.02	43.33
80.	54.43	5.14	45.96	62.89	26.15	9.51	10.50	41.80
90.	52.86	5.08	44.51	61.22	26.32	8.07	13.04	39.60
100.	49.56	5.61	40.33	58.78	25.98	4.63	18.36	33.59
110.	43.67	6.97	32.21	55.13	23.44	5.76	13.97	32.91
120.	33.56	8.98	18.78	48.34	18.53	4.58	11.00	26.07
130.	32.27	4.60	24.69	39.84	17.00	3.21	11.71	22.28
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Concluded

AZIMUTH ANGLE -45. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	37.30	4.33	30.18	44.42	35.68	2.76	31.15	40.21
30.	37.71	3.89	31.32	44.11	32.54	8.65	18.31	46.77
40.	39.26	3.94	32.78	45.75	33.01	11.99	13.28	52.73
50.	39.94	3.52	34.15	45.72	31.88	13.50	9.67	54.08
60.	40.32	3.30	34.89	45.74	30.61	15.15	5.69	55.53
70.	40.07	3.16	34.87	45.28	30.18	14.63	6.11	54.25
80.	39.68	3.26	34.33	45.04	30.37	13.80	7.68	53.07
90.	38.88	3.17	33.67	44.09	31.27	10.82	13.48	49.06
100.	37.14	3.53	31.33	42.95	31.31	7.96	18.22	44.40
110.	32.97	5.25	24.33	41.60	28.62	5.46	19.63	37.60
120.	24.20	7.67	11.58	36.82	21.32	7.29	9.33	33.31
130.	24.10	7.24	12.19	36.02	20.99	9.49	5.37	36.61
140.	17.81	0.00	17.81	17.81	16.20	0.00	16.20	16.20

Table 7. Summary Statistics for Restrained Females (cm)

AZIMUTH ANGLE 120. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	21.39	6.00	11.52	31.25	40.52	10.24	23.68	57.37
10.	24.95	2.25	21.25	28.65	45.87	4.43	38.58	53.17
20.	29.64	2.32	25.82	33.46	53.63	3.42	48.00	59.26
30.	32.39	2.31	28.60	36.18	58.39	3.12	53.25	63.53
40.	34.35	2.10	30.90	37.80	61.36	3.23	56.04	66.68
50.	34.70	2.36	30.83	38.58	62.35	3.23	57.04	67.67
60.	34.74	2.58	30.49	38.99	62.73	3.24	57.39	68.06
70.	33.67	2.55	29.47	37.87	60.77	3.48	55.04	66.49
80.	31.80	2.59	27.55	36.06	57.55	3.61	51.62	63.49
90.	28.33	[illegible].69	23.90	32.75	52.16	3.99	45.59	58.73
100.	22.54	3.24	17.21	27.86	43.36	4.82	35.43	51.30
110.	14.87	4.26	7.86	21.87	31.79	4.74	24.00	39.58
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Continued

AZIMUTH ANGLE 105. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	9.19	0.00	9.19	9.19	45.78	0.00	45.78	45.78
10.	12.14	1.37	9.88	14.40	51.58	4.49	44.19	58.96
20.	14.40	1.36	12.16	16.64	60.68	3.73	54.55	66.81
30.	15.88	1.29	13.76	18.01	65.62	3.37	60.07	71.17
40.	16.51	1.32	14.35	18.68	69.15	3.45	63.48	74.81
50.	16.68	1.50	14.21	19.14	70.27	3.35	64.76	75.79
60.	16.76	1.53	14.25	19.27	70.31	3.51	64.54	76.08
70.	16.25	1.42	13.92	18.59	68.08	3.63	62.10	74.06
80.	15.30	1.60	12.67	17.93	64.64	3.93	58.17	71.11
90.	13.62	1.86	10.56	16.68	58.99	4.37	51.81	66.17
100.	10.81	2.31	7.01	14.61	49.78	5.76	40.31	59.24
110.	7.65	2.71	3.19	12.11	37.59	6.53	26.84	48.34
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Continued

AZIMUTH ANGLE 90. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	1.39	0.72	0.20	2.57	52.75	4.19	45.86	59.64
20.	1.55	0.88	0.10	2.99	62.44	3.71	56.34	68.54
30.	1.56	0.65	0.49	2.63	68.14	3.35	62.30	73.98
40.	1.77	0.58	0.82	2.72	71.65	3.31	66.20	77.09
50.	1.84	0.54	0.94	2.73	72.67	3.42	67.05	78.29
60.	1.74	0.79	0.43	3.05	72.73	3.54	66.91	78.56
70.	1.80	0.69	0.67	2.93	70.44	3.74	64.30	76.59
80.	1.89	0.64	0.84	2.93	66.81	4.21	59.89	73.73
90.	1.97	0.82	0.63	3.32	60.80	4.57	53.28	68.32
100.	2.23	0.92	0.72	3.73	51.12	6.28	40.78	61.45
110.	2.74	0.83	1.37	4.11	39.89	5.89	30.20	49.57
120.	1.33	0.00	1.33	1.33	25.90	0.00	25.90	25.90
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

AZIMUTH ANGLE 75. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	12.37	0.00	12.37	12.37	45.61	0.00	45.61	45.61
10.	14.74	1.19	12.79	16.69	50.05	4.24	43.08	57.02
20.	17.16	1.14	15.29	19.03	59.43	3.67	53.39	65.47
30.	18.66	1.17	16.74	20.59	64.82	3.23	59.51	70.13
40.	19.96	2.03	16.63	23.30	67.31	4.36	60.14	74.48
50.	20.24	1.94	17.05	23.43	68.53	4.11	61.77	75.29
60.	20.04	1.40	17.73	22.34	69.21	3.26	63.85	74.57
70.	19.32	1.33	17.13	21.52	67.18	3.46	61.48	72.87
80.	18.42	1.50	15.96	20.88	63.47	3.93	57.01	69.94
90.	17.05	1.71	14.23	19.86	57.39	4.63	49.78	65.01
100.	14.71	1.96	11.49	17.93	47.77	6.21	37.55	57.98
110.	11.95	1.95	8.75	15.16	37.36	5.56	28.21	46.51
120.	8.53	0.00	8.53	8.53	23.99	0.00	23.99	23.99
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Continued

AZIMUTH ANGLE 60. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	26.42	2.67	22.03	30.80	44.14	3.97	37.61	50.67
20.	31.44	2.38	27.54	35.35	51.64	3.22	46.34	56.94
30.	34.43	2.11	30.95	37.90	56.58	3.02	51.61	61.54
40.	36.22	2.08	32.80	39.64	59.44	2.76	54.91	63.98
50.	36.93	2.02	33.61	40.25	60.45	2.72	55.98	64.92
60.	36.91	1.98	33.64	40.17	60.48	2.83	55.83	65.13
70.	36.08	2.27	32.34	39.81	58.60	2.83	53.94	63.26
80.	34.42	3.00	29.48	39.35	55.08	3.21	49.79	60.37
90.	30.91	2.58	26.66	35.15	49.65	4.01	43.06	56.25
100.	25.85	3.23	20.53	31.16	41.53	4.76	33.70	49.36
110.	19.30	3.70	13.22	25.39	30.79	4.77	22.94	38.64
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Continued

AZIMUTH ANGLE 45. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	33.07	2.38	29.16	36.98	33.22	2.13	29.72	36.73
20.	40.55	2.24	36.86	44.23	40.04	2.30	36.25	43.83
30.	44.82	2.57	40.60	49.04	44.69	2.40	40.75	48.63
40.	47.55	3.27	42.16	52.93	46.88	2.41	42.91	50.84
50.	48.28	2.77	43.72	52.84	47.60	2.36	43.72	51.43
60.	48.07	2.33	44.24	51.90	47.51	2.24	43.83	51.20
70.	46.75	2.48	42.68	50.83	46.29	2.30	42.51	50.08
80.	44.22	2.89	39.47	48.98	43.70	2.68	39.29	48.12
90.	40.07	3.53	34.27	45.87	39.37	3.22	34.07	44.66
100.	33.22	4.40	25.98	40.45	32.58	4.46	25.24	39.91
110.	25.26	3.84	18.94	31.57	24.31	4.49	16.93	31.70
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Continued

AZIMUTH ANGLE 30. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	37.63	2.48	33.55	41.70	23.83	5.07	15.50	32.17
20.	45.40	2.55	41.20	49.59	28.22	4.04	21.57	34.86
30.	50.33	2.69	45.91	54.75	31.40	4.57	23.88	38.92
40.	53.08	2.51	48.95	57.22	33.14	4.92	25.04	41.23
50.	54.24	2.48	50.17	58.32	33.52	4.58	25.98	41.05
60.	54.38	2.46	50.33	58.44	33.21	4.29	26.16	40.27
70.	52.77	2.82	48.13	57.40	32.20	4.14	25.40	39.01
80.	49.96	3.25	44.62	55.31	30.48	4.25	23.49	37.48
90.	44.60	4.17	37.74	51.46	26.95	4.33	19.82	34.08
100.	36.47	5.64	27.19	45.76	21.65	4.50	14.25	29.06
110.	28.00	5.92	18.27	37.74	17.20	4.17	10.34	24.05
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Continued

AZIMUTH ANGLE 15. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	39.22	3.12	34.09	44.36	13.04	4.77	5.20	20.88
20.	46.51	2.86	41.80	51.22	14.90	3.59	8.99	20.81
30.	51.69	2.85	47.01	56.37	16.05	3.90	9.64	22.46
40.	54.48	2.51	50.34	58.61	16.50	3.98	9.95	23.05
50.	55.41	2.48	51.33	59.49	16.76	4.06	10.07	23.44
60.	55.59	2.60	51.31	59.87	16.81	3.99	10.25	23.37
70.	54.29	2.65	49.93	58.64	16.07	3.81	9.80	22.34
80.	51.25	3.25	45.91	56.59	14.79	3.87	8.41	21.16
90.	45.54	4.22	38.59	52.49	13.31	3.60	7.38	19.24
100.	35.66	6.74	24.57	46.76	10.84	3.42	5.21	16.47
110.	26.11	6.51	15.41	36.82	8.91	3.71	2.81	15.02
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Continued

AZIMUTH ANGLE 0. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	39.90	4.12	33.12	46.67	1.13	0.20	0.80	1.45
20.	44.46	3.58	38.57	50.34	1.18	0.39	0.53	1.82
30.	49.32	3.11	44.20	54.45	1.06	0.24	0.67	1.45
40.	52.03	2.86	47.32	56.74	1.02	0.29	0.55	1.49
50.	53.04	2.81	48.42	57.66	1.15	0.54	0.27	2.04
60.	53.16	2.93	48.34	57.99	1.37	0.82	0.02	2.72
70.	52.14	3.03	47.16	57.12	1.24	0.35	0.65	1.82
80.	49.04	3.76	42.85	55.23	1.18	0.34	0.62	1.73
90.	42.98	5.60	33.77	52.20	1.18	0.30	0.69	1.67
100.	31.76	9.31	16.44	47.08	1.47	0.38	0.84	2.09
110.	18.25	10.35	1.23	35.28	1.46	0.24	1.06	1.87
120.	16.63	0.00	16.63	16.63	1.37	0.00	1.37	1.37
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Continued

AZIMUTH ANGLE -15. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	40.04	0.00	40.04	40.04	9.69	0.00	9.69	9.69
30.	40.53	3.47	34.82	46.25	9.81	1.17	7.89	11.74
40.	44.07	4.19	37.18	50.96	11.27	1.86	8.21	14.33
50.	45.14	4.39	37.92	52.37	11.51	2.00	8.22	14.79
60.	45.57	4.74	37.78	53.36	11.39	1.94	8.20	14.59
70.	44.77	4.56	37.27	52.27	11.12	1.55	8.58	13.66
80.	41.52	5.12	33.11	49.94	10.10	2.06	6.72	13.49
90.	35.95	6.01	26.07	45.84	8.18	2.34	4.33	12.04
100.	26.56	7.66	13.96	39.16	5.88	2.68	1.46	10.29
110.	32.05	0.00	32.05	32.05	7.97	0.00	7.97	7.97
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Continued

AZIMUTH ANGLE -30. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30.	31.27	4.62	23.68	38.86	17.19	2.85	12.50	21.89
40.	33.77	4.33	26.64	40.90	18.77	3.13	13.62	23.91
50.	34.68	4.65	27.03	42.33	19.73	3.00	14.80	24.67
60.	34.82	4.77	26.98	42.66	19.90	3.27	14.52	25.27
70.	33.47	5.18	24.94	42.00	18.97	3.57	13.09	24.84
80.	30.79	5.56	21.64	39.95	17.11	4.06	10.43	23.79
90.	25.92	5.93	16.16	35.68	14.08	4.74	6.29	21.87
100.	19.31	6.23	9.06	29.55	9.90	4.40	2.66	17.14
110.	22.83	2.57	18.60	27.06	11.68	2.81	7.06	16.29
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Concluded

AZIMUTH ANGLE -45. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	23.07	0.00	23.07	23.07	19.46	0.00	19.46	19.46
30.	23.00	4.10	16.26	29.74	20.14	4.32	13.03	27.25
40.	23.54	4.50	16.13	30.95	21.17	4.58	13.63	28.70
50.	23.50	4.89	15.45	31.54	21.03	5.00	12.81	29.25
60.	23.63	5.53	13.92	32.13	20.52	5.61	11.39	29.86
70.	21.63	5.42	12.72	30.54	19.25	5.60	10.04	28.47
80.	20.03	5.21	11.47	28.59	17.26	5.65	7.96	26.56
90.	16.94	4.88	8.92	24.96	13.82	5.66	4.52	23.13
100.	12.72	4.90	4.67	20.78	10.25	5.67	0.93	19.57
110.	9.98	8.01	-3.20	23.16	9.72	7.43	-2.50	21.94
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Summary Statistics for Unrestrained Females (cm)

AZIMUTH ANGLE 120. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	18.96	2.40	15.02	22.90	39.09	2.86	34.40	43.79
10.	25.33	2.57	21.09	29.56	45.80	4.79	37.91	53.68
20.	29.84	2.46	25.79	33.89	53.40	4.09	46.66	60.13
30.	32.34	2.26	28.63	36.06	57.74	3.52	51.95	63.52
40.	33.88	2.39	29.94	37.81	60.67	3.49	54.92	66.41
50.	34.30	2.36	30.43	38.18	61.14	3.54	55.31	66.97
60.	34.33	2.58	30.09	38.57	61.08	3.77	54.87	67.28
70.	33.19	2.82	28.55	37.83	58.93	4.05	52.28	65.59
80.	31.41	3.05	26.39	36.42	56.08	4.28	49.04	63.12
90.	28.31	3.11	23.20	33.42	51.27	4.70	43.54	59.00
100.	23.72	3.85	17.39	30.06	43.77	5.42	34.86	52.69
110.	17.72	4.65	10.07	25.36	34.22	5.83	24.63	43.82
120.	14.24	4.80	6.34	22.14	26.36	5.63	17.10	35.62
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE 105. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	10.91	1.16	9.00	12.81	47.43	5.79	37.90	56.96
10.	11.90	1.37	9.64	14.15	50.59	5.04	42.30	58.87
20.	14.45	1.29	12.34	16.57	59.98	4.36	52.82	67.15
30.	15.73	1.29	13.66	17.90	65.03	3.81	58.77	71.29
40.	16.45	1.60	13.81	19.08	68.52	3.67	62.49	74.55
50.	16.49	1.35	14.26	18.72	69.19	3.90	62.78	75.61
60.	16.41	1.13	14.56	18.27	69.04	4.20	62.12	75.95
70.	15.81	1.23	13.79	17.83	66.79	4.12	60.01	73.57
80.	14.92	1.78	11.99	17.86	63.32	4.44	56.01	70.63
90.	13.34	1.92	10.19	16.49	57.63	5.13	49.19	66.07
100.	10.99	1.99	7.72	14.26	50.07	5.83	40.48	59.65
110.	8.05	2.25	4.34	11.76	38.21	6.60	27.34	49.07
120.	6.14	2.47	2.07	10.21	28.55	6.47	17.90	39.20
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE 90. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	1.21	0.60	0.22	2.21	46.39	7.49	34.08	58.71
10.	1.47	0.73	0.27	2.67	53.97	5.82	44.40	63.55
20.	1.41	0.53	0.53	2.28	63.11	5.14	54.65	71.56
30.	1.52	0.49	0.71	2.33	68.26	4.92	60.17	76.35
40.	1.78	0.70	0.62	2.94	71.62	4.72	63.84	79.39
50.	1.70	0.64	0.65	2.75	72.26	4.52	64.82	79.70
60.	1.58	0.68	0.47	2.70	72.18	4.51	64.76	79.59
70.	1.62	0.58	0.67	2.57	69.63	4.65	61.98	77.27
80.	1.69	0.65	0.62	2.76	65.99	4.72	58.22	73.75
90.	1.70	0.58	0.74	2.66	60.26	4.92	52.16	68.36
100.	2.00	1.01	0.34	3.66	52.03	5.97	42.21	61.85
110.	2.23	1.20	0.25	4.21	39.13	7.83	26.25	52.02
120.	2.67	0.47	1.90	3.43	30.40	4.24	23.42	37.38
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE 75. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	15.05	2.67	10.65	19.45	51.79	10.05	35.26	68.31
10.	15.82	1.72	12.99	18.65	53.55	7.36	41.44	65.65
20.	18.06	1.82	15.08	21.05	61.98	5.95	52.19	71.78
30.	19.24	1.70	16.44	22.03	66.79	5.17	58.29	75.29
40.	19.98	1.52	17.48	22.49	69.76	4.72	62.00	77.52
50.	20.26	1.39	17.97	22.55	70.31	4.41	63.06	77.56
60.	20.27	1.43	17.92	22.62	70.04	4.20	63.12	76.95
70.	19.68	1.46	17.28	22.08	67.59	4.32	60.47	74.70
80.	18.81	1.62	16.14	21.47	64.03	4.66	56.37	71.69
90.	17.52	1.66	14.79	20.26	58.39	5.01	50.15	66.64
100.	15.65	1.82	12.66	18.64	49.99	6.30	39.62	60.36
110.	13.08	2.40	9.12	17.04	37.90	8.00	24.75	51.06
120.	11.70	0.70	10.55	12.86	32.43	0.87	31.00	33.86
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE 60. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	25.90	2.49	21.81	29.99	41.72	6.05	31.77	51.66
10.	28.93	3.11	23.81	34.05	46.98	4.67	39.29	54.66
20.	33.76	3.07	28.71	38.82	55.24	4.11	48.48	62.00
30.	36.40	2.94	31.56	41.23	59.66	4.10	52.92	66.41
40.	37.83	2.67	33.43	42.22	62.07	4.14	55.26	68.87
50.	38.10	2.46	34.06	42.15	62.74	4.00	56.16	69.31
60.	38.02	2.46	33.97	42.07	62.81	4.37	55.62	70.00
70.	37.07	2.37	33.17	40.98	60.64	3.72	54.52	66.76
80.	35.48	2.53	31.33	39.64	57.25	4.01	50.66	63.84
90.	32.93	2.85	28.23	37.63	52.10	4.12	45.33	58.88
100.	28.85	3.80	22.60	35.10	44.63	5.55	35.50	53.76
110.	22.48	4.15	15.65	29.31	33.12	6.80	21.92	44.31
120.	16.23	1.13	14.36	18.09	21.23	2.21	17.59	24.86
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE 45. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	42.04	0.00	42.04	42.04	41.73	0.00	41.73	41.73
10.	38.45	4.62	30.86	46.04	38.39	4.63	30.78	45.99
20.	45.76	5.47	36.76	54.76	45.37	5.87	35.71	55.03
30.	49.36	4.80	41.46	57.26	48.49	6.00	38.62	58.36
40.	51.42	4.25	44.43	58.41	50.76	4.57	43.25	58.27
50.	52.19	3.90	45.77	58.62	51.55	4.06	44.86	58.23
60.	52.09	3.72	45.97	58.21	51.23	3.82	44.95	57.51
70.	50.82	3.65	44.82	56.82	49.71	3.51	43.94	55.49
80.	48.87	3.89	42.47	55.26	47.31	3.51	41.53	53.09
90.	45.47	4.61	37.89	53.04	43.56	3.98	37.02	50.11
100.	38.07	6.32	27.67	48.47	36.51	4.68	28.81	44.21
110.	30.08	6.08	20.08	40.07	27.08	5.64	17.81	36.36
120.	25.09	3.77	18.69	31.29	21.82	3.15	16.63	27.02
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE 30. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	62.78	3.72	56.67	68.89	17.54	16.62	-9.80	44.88
10.	49.79	10.44	32.61	66.96	26.79	8.02	13.60	39.99
20.	57.09	8.73	42.74	71.45	31.58	8.68	17.30	45.87
30.	60.87	7.56	48.43	73.31	33.41	9.07	18.49	48.33
40.	62.82	7.11	51.13	74.51	34.20	9.25	18.98	49.42
50.	63.22	6.28	52.88	73.56	34.46	9.14	19.43	49.49
60.	62.77	5.65	53.48	72.06	34.36	8.93	19.68	49.05
70.	61.42	5.09	53.05	69.80	33.32	8.63	19.13	47.52
80.	59.33	4.79	51.45	67.22	31.74	8.41	17.91	45.58
90.	55.02	5.22	46.43	63.60	29.09	7.93	16.04	42.14
100.	47.97	6.38	37.47	58.46	25.07	7.32	13.04	37.10
110.	38.27	4.91	30.20	46.34	20.09	6.27	9.77	30.41
120.	24.65	9.43	9.13	40.16	11.59	7.53	-0.79	23.97
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE 15. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	70.03	0.40	69.38	70.68	9.60	12.61	-11.15	30.35
10.	53.09	9.92	36.77	69.41	14.64	4.13	7.85	21.43
20.	60.96	7.72	48.26	73.66	16.66	4.44	9.35	23.97
30.	64.30	6.67	53.32	75.27	17.52	4.36	10.34	24.69
40.	66.03	6.39	55.51	76.55	17.94	4.38	10.73	25.15
50.	66.57	6.26	56.27	76.87	17.84	4.36	10.67	25.00
60.	66.90	6.33	56.49	77.31	17.56	4.38	10.35	24.77
70.	66.43	6.56	55.64	77.22	17.05	4.36	9.88	24.23
80.	64.99	6.98	53.51	76.48	16.31	4.28	9.27	23.34
90.	61.48	7.48	49.17	73.78	15.21	4.16	8.38	22.05
100.	54.53	9.15	39.46	69.60	13.35	3.77	7.15	19.56
110.	42.24	10.02	25.76	58.72	10.39	3.51	4.60	16.17
120.	32.39	8.23	18.85	45.92	6.03	4.11	-0.73	12.80
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE 0. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	51.96	4.47	44.61	59.31	1.00	0.06	0.90	1.10
10.	52.69	8.27	39.09	66.30	1.13	0.28	0.66	1.60
20.	60.44	7.35	48.34	72.53	2.02	4.30	-5.05	9.09
30.	63.70	5.97	53.88	73.53	2.05	4.50	-5.34	9.47
40.	65.04	5.96	55.23	74.85	3.89	8.82	-10.63	18.40
50.	65.84	6.28	55.51	76.17	4.03	9.25	-11.19	19.25
60.	66.16	6.58	55.33	76.98	4.04	9.41	-11.45	19.52
70.	65.67	6.40	55.15	76.20	4.07	9.37	-11.35	19.49
80.	63.78	7.10	52.11	75.45	3.04	8.96	-10.70	18.78
90.	59.66	8.09	46.35	72.97	3.83	8.44	-10.06	17.71
100.	51.72	9.61	35.91	67.52	3.63	7.37	-8.49	15.75
110.	36.70	12.02	16.93	56.46	3.59	6.46	-7.03	14.21
120.	23.84	[illegible]	-2.51	50.20	5.03	5.24	-3.58	13.65
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE -15. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	50.74	6.53	40.00	61.49	13.07	2.40	9.13	17.02
30.	53.91	6.48	43.25	64.57	14.38	1.94	11.19	17.57
40.	55.37	7.75	42.62	68.12	15.87	2.49	11.77	19.97
50.	56.49	8.10	43.16	69.82	15.03	3.63	9.05	21.01
60.	57.76	7.27	45.81	69.72	16.36	1.72	13.53	19.18
70.	57.92	6.03	48.00	67.84	17.02	5.65	7.72	26.32
80.	56.83	5.38	47.98	65.68	16.68	6.82	5.47	27.89
90.	53.56	5.36	44.75	62.37	15.44	6.76	4.32	26.56
100.	46.72	6.46	36.10	57.34	13.37	6.53	2.63	24.12
110.	36.58	7.64	24.01	49.15	12.36	7.91	-0.66	25.38
120.	28.55	10.29	11.62	45.47	14.35	7.20	2.50	26.19
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 8. Continued

AZIMUTH ANGLE -30. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	37.99	2.07	34.59	41.39	24.34	2.69	19.91	28.76
30.	44.18	6.16	34.05	54.31	26.01	6.29	15.67	36.35
40.	47.18	5.88	37.51	56.86	27.98	5.58	18.79	37.16
50.	48.77	5.74	39.33	58.22	28.84	5.21	20.26	37.41
60.	49.88	5.59	40.68	59.07	29.34	4.97	21.16	37.53
70.	49.34	5.65	40.05	58.64	28.44	5.22	19.86	37.03
80.	47.94	5.68	38.60	57.28	26.96	5.70	17.58	36.34
90.	44.94	5.58	35.75	54.12	25.06	5.73	15.64	34.48
100.	39.67	5.32	30.93	48.42	22.77	3.80	16.53	29.01
110.	30.10	5.76	20.63	39.58	17.83	6.50	7.13	28.53
120.	27.12	6.97	15.67	38.58	19.83	13.38	-2.18	41.84
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

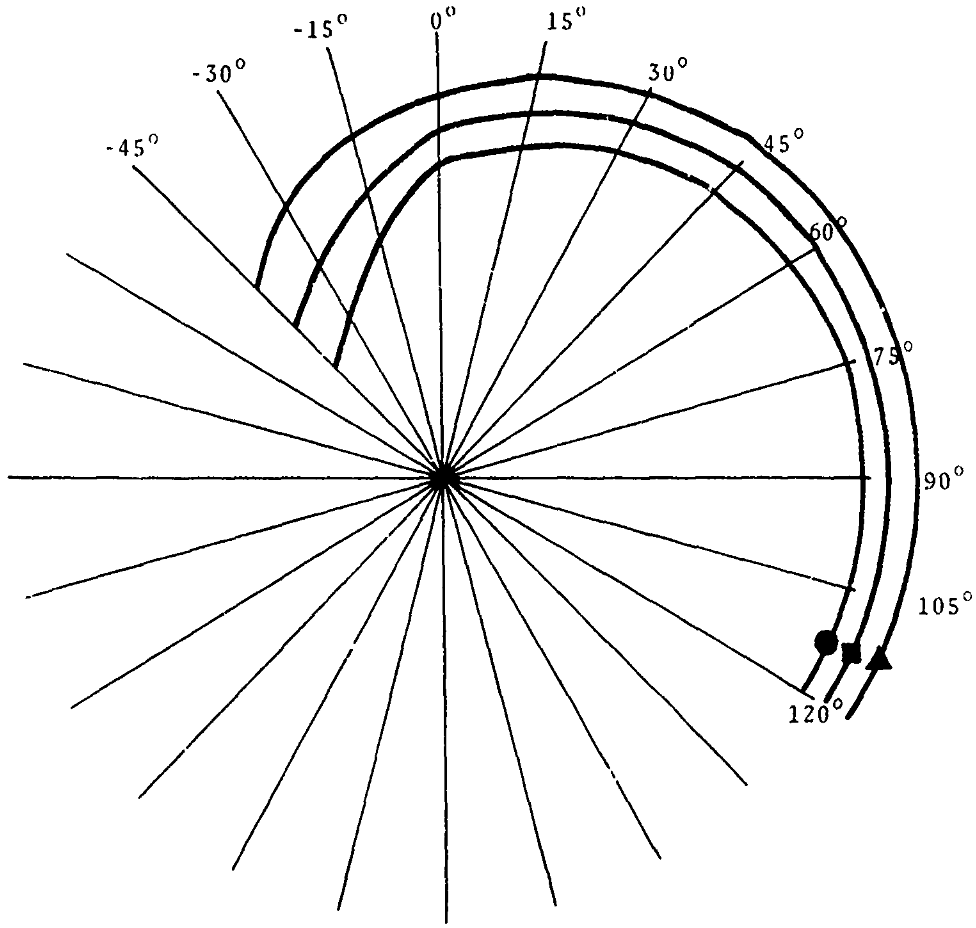
Table 8. Concluded

AZIMUTH ANGLE -45. DEGREES

ALT.	MEAN X	S.D. X	5TH X	95TH X	MEAN Y	S.D. Y	5TH Y	95TH Y
0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20.	30.65	3.90	24.23	37.06	31.62	3.98	25.08	38.16
30.	34.67	3.64	28.68	40.66	34.17	3.45	28.50	39.84
40.	37.19	3.76	31.00	43.38	37.01	3.46	31.31	42.71
50.	38.62	3.74	32.48	44.77	38.28	3.34	32.77	43.78
60.	39.60	3.71	33.50	45.70	38.81	3.14	33.65	43.98
70.	39.12	3.59	33.22	45.02	37.87	3.34	32.38	43.36
80.	38.26	4.01	31.66	44.87	36.28	3.53	30.47	42.09
90.	36.55	5.29	27.85	45.25	33.50	3.98	26.95	40.04
100.	31.62	4.72	23.86	39.37	28.88	4.48	21.52	36.24
110.	23.56	4.68	15.87	31.26	21.02	4.83	13.06	28.97
120.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
130.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
140.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 9. Reach Envelope Comparison Unrestrained Males
50-cm (20-inch) Altitude

	Texas Tech Data (inches)			Kennedy (1964) Data (inches)		
Azimuth	5th Percentile	$\bar{X}$ (50th Percentile)	95th Percentile	5th Percentile	50th Percentile	95th Percentile
120°	27.98	30.58	33.18	30.50	33.00	35.50
105°	27.80	31.00	34.21	31.75	33.50	35.75
90°	27.27	31.69	36.11	32.25	34.00	36.00
75°	27.48	31.98	36.48	32.25	34.00	36.50
60°	27.63	32.29	36.95	32.00	33.75	36.25
45°	27.15	32.59	38.02	31.00	33.50	36.25
30°	25.42	32.36	39.35	30.00	32.00	35.75
15°	24.26	30.43	36.67	28.00	30.50	34.00
0°	23.84	29.01	34.39	25.50	28.75	31.75
-15°	22.35	27.33	32.33	23.50	26.75	29.75
-30°	18.40	23.89	30.16	21.50	24.75	28.25
-45°	13.97	20.12	27.88	19.50	22.75	26.75

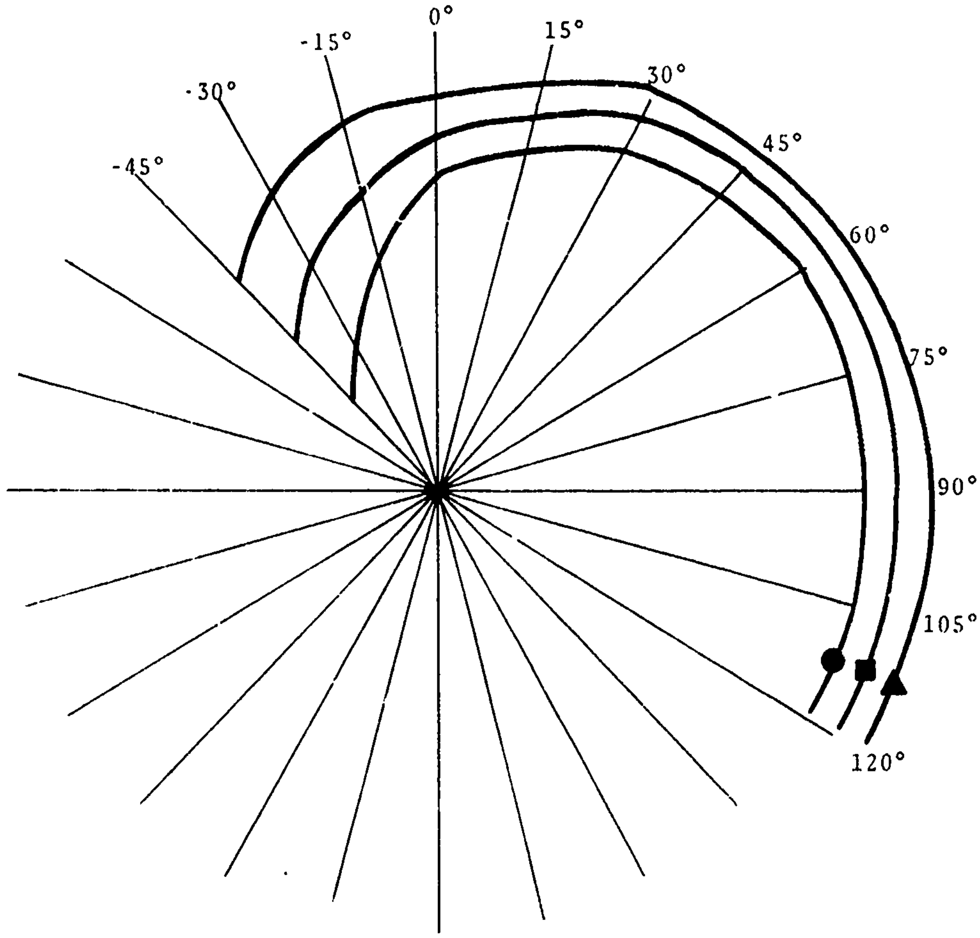


● 5th Percentile

■ 50th Percentile

▲ 95th Percentile

Figure 8. Reach Envelope for Restrained Males 60-cm Altitude.

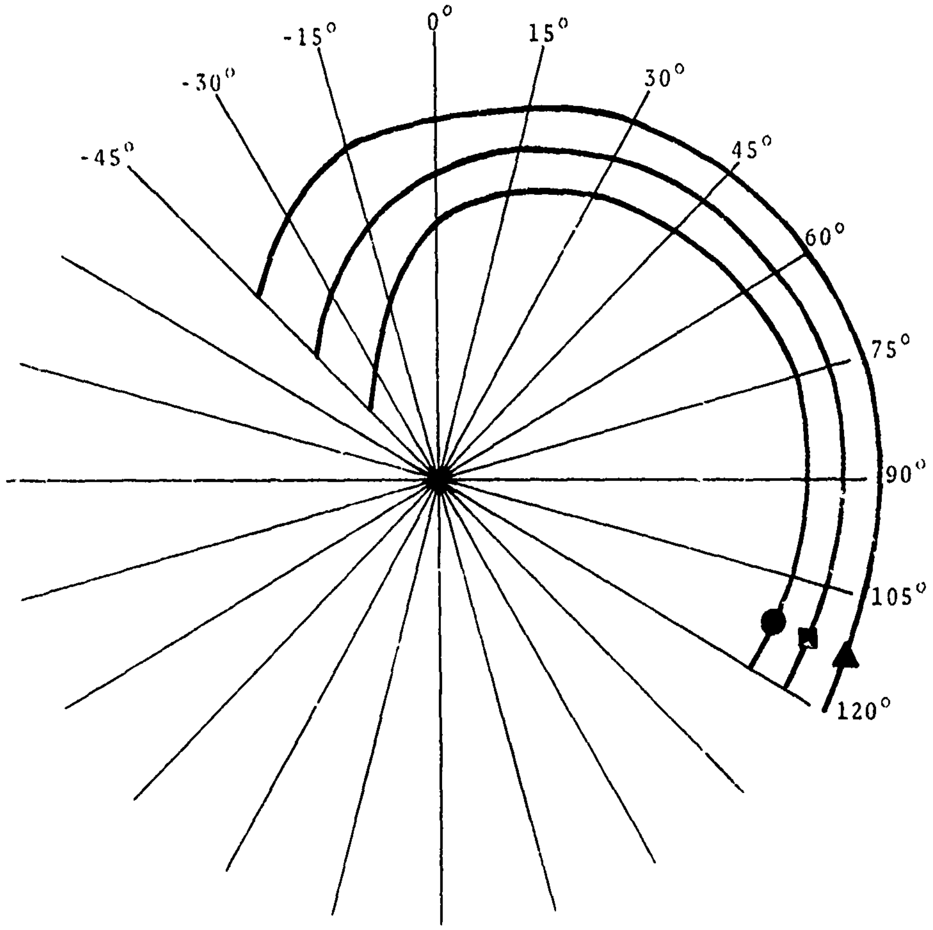


● 5th Percentile

■ 50th Percentile

▲ 95th Percentile

Figure 8. Reach Envelope for Restrained Males 60-cm Altitude.

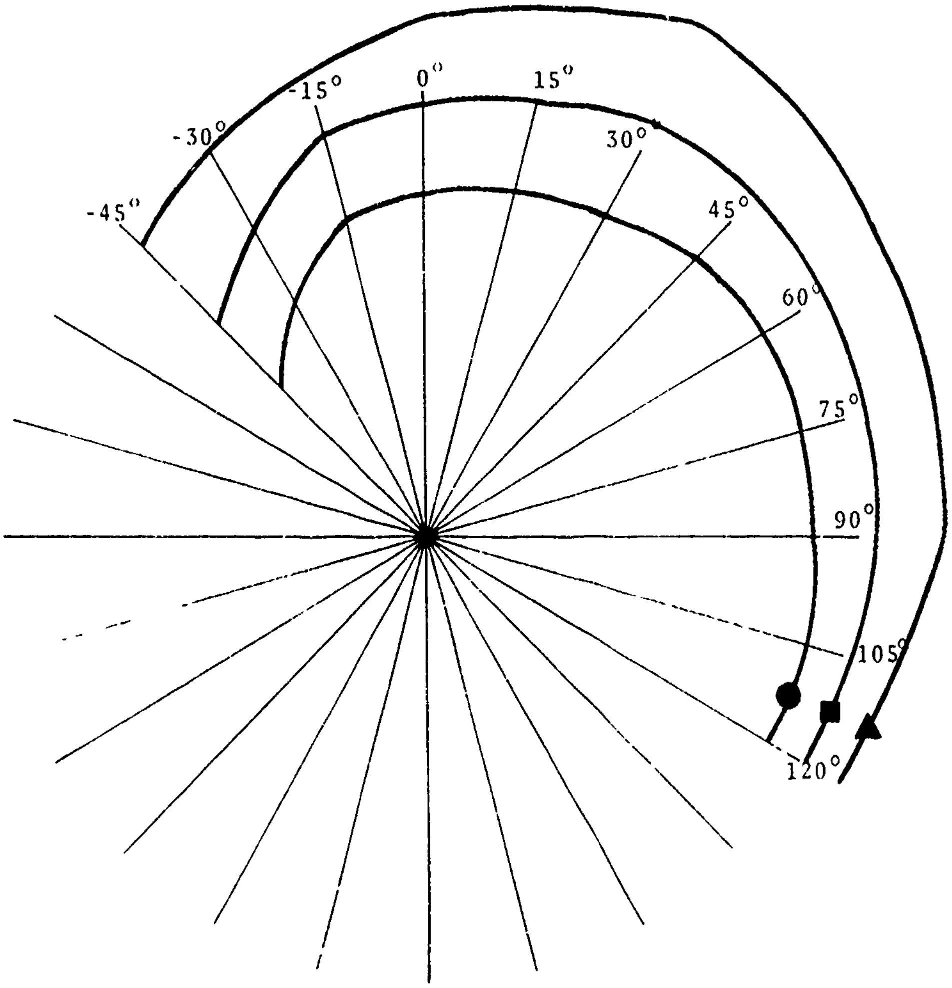


● 5th Percentile

■ 50th Percentile

▲ 95th Percentile

Figure 9. Reach Envelope for Restrained Males
90-cm Altitude.

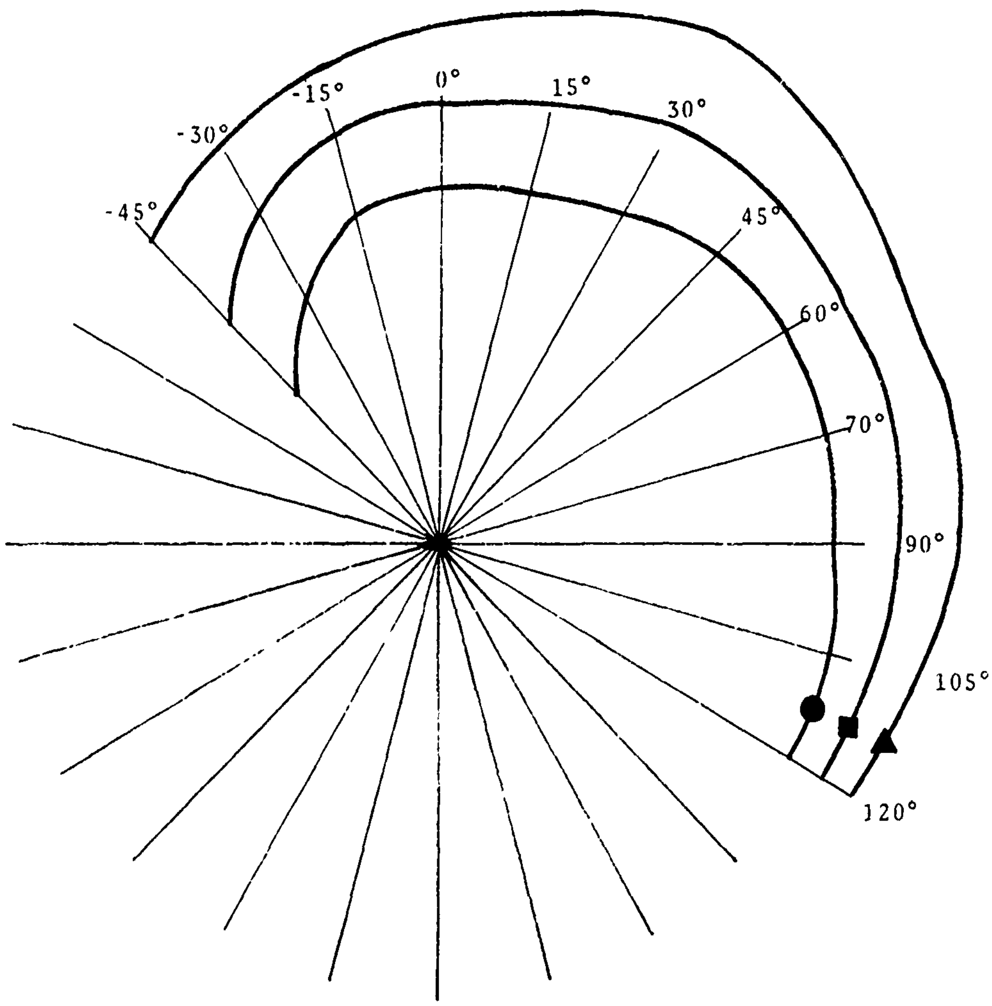


5th Percentile

50th Percentile

95th Percentile

Figure 10. Reach Envelope for Unrestrained Males 40-cm Altitude.



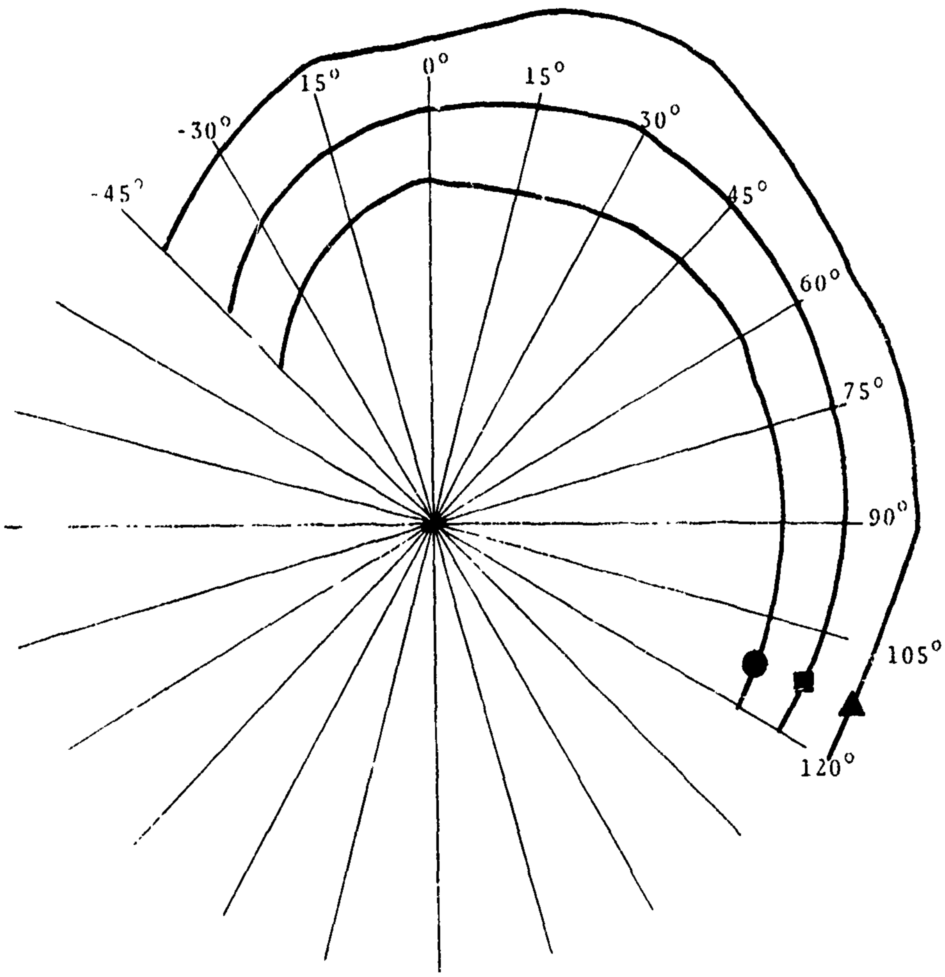
● 5th Percentile

■ 50th Percentile

▲ 95th Percentile

Figure 11. Reach Envelope for Unrestrained Males

60-cm Altitude

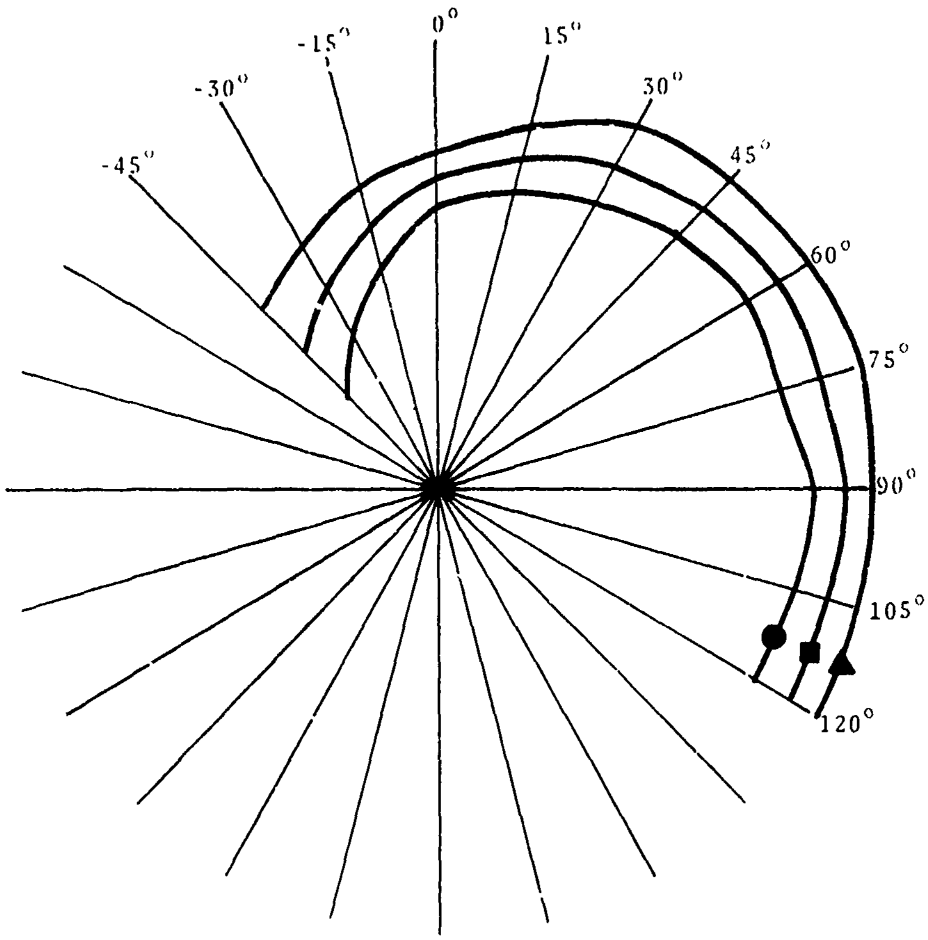


● 5th Percentile

■ 50th Percentile

▲ 95th Percentile

Figure 12. Reach Envelope for Unrestrained Males 90-cm Altitude.

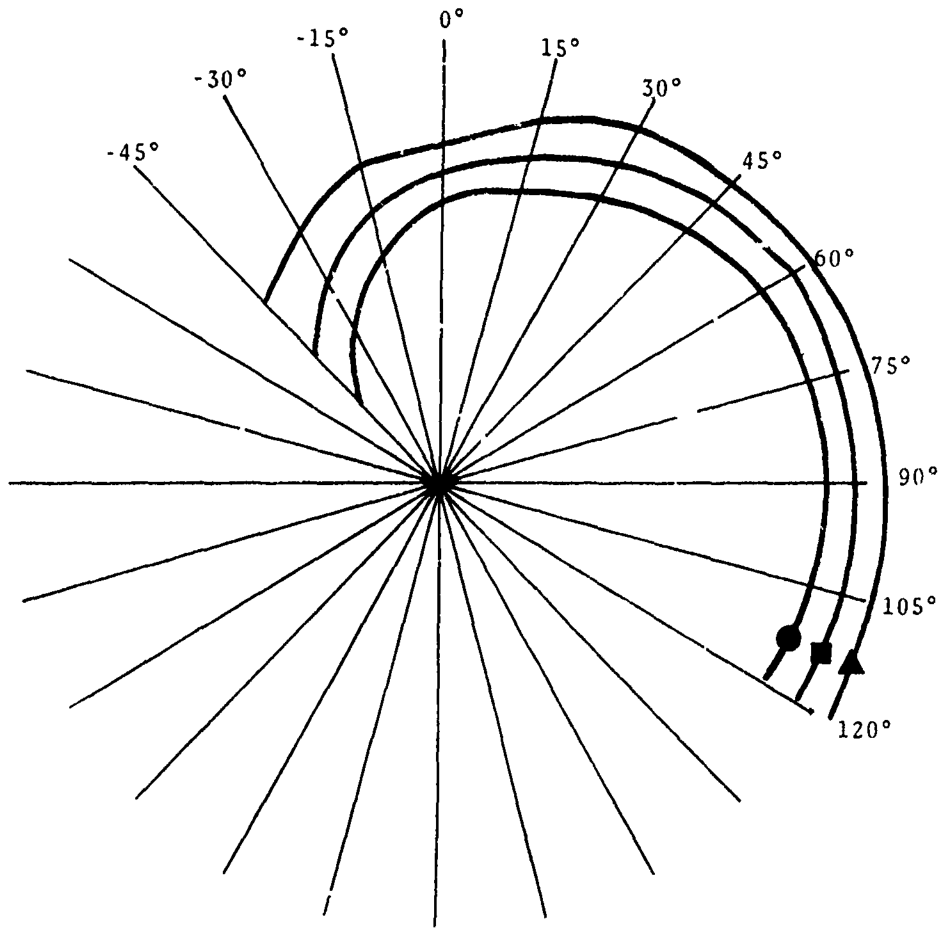


5th Percentile

50th Percentile

95th Percentile

Figure 13. Reach Envelope for Restrained Females 40-cm Altitude.

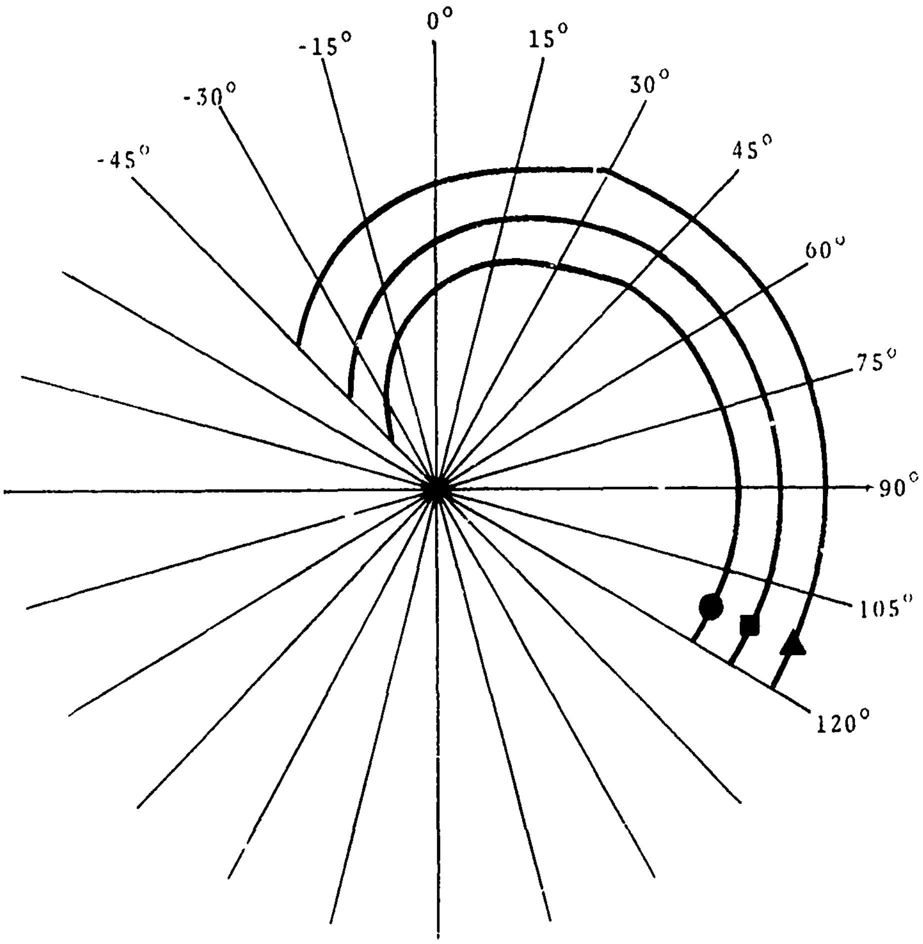


5th Percentile

50th Percentile

95th Percentile

Figure 14. Reach Envelope for Restrained Females 60-cm Altitude.

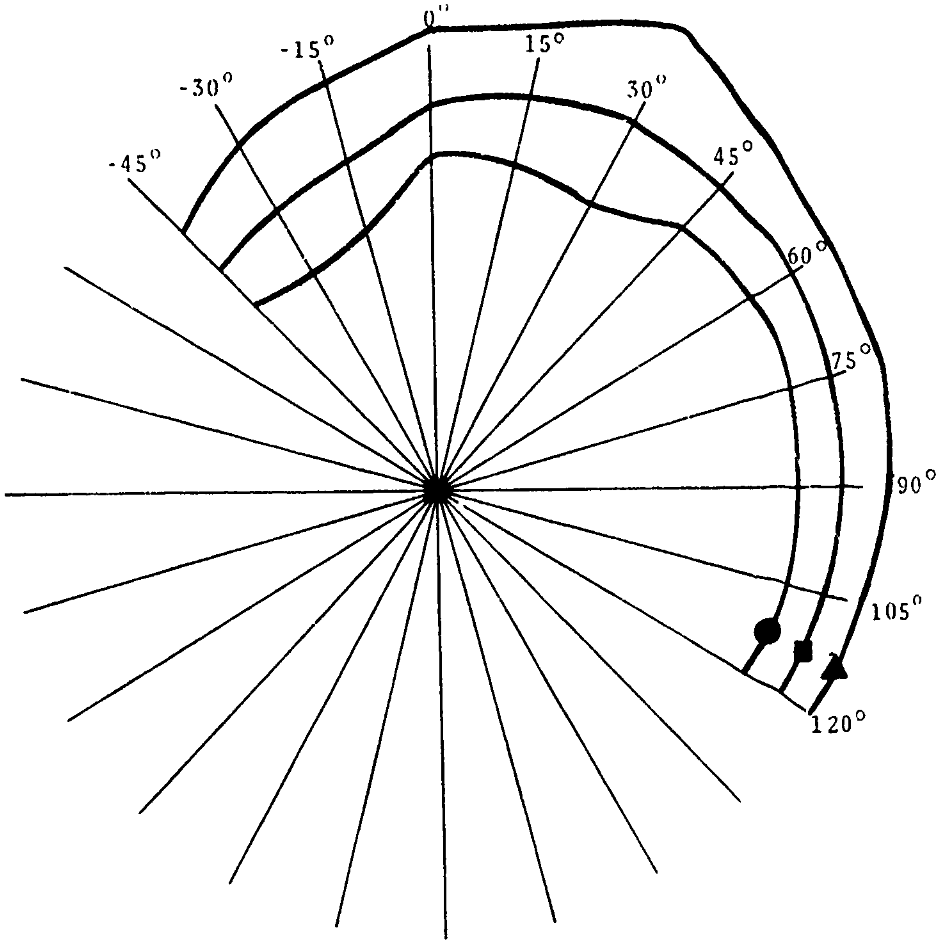


● 5th Percentile

■ 50th Percentile

▲ 95th Percentile

Figure 15. Reach Envelope for Restrained Females 90-cm Altitude.



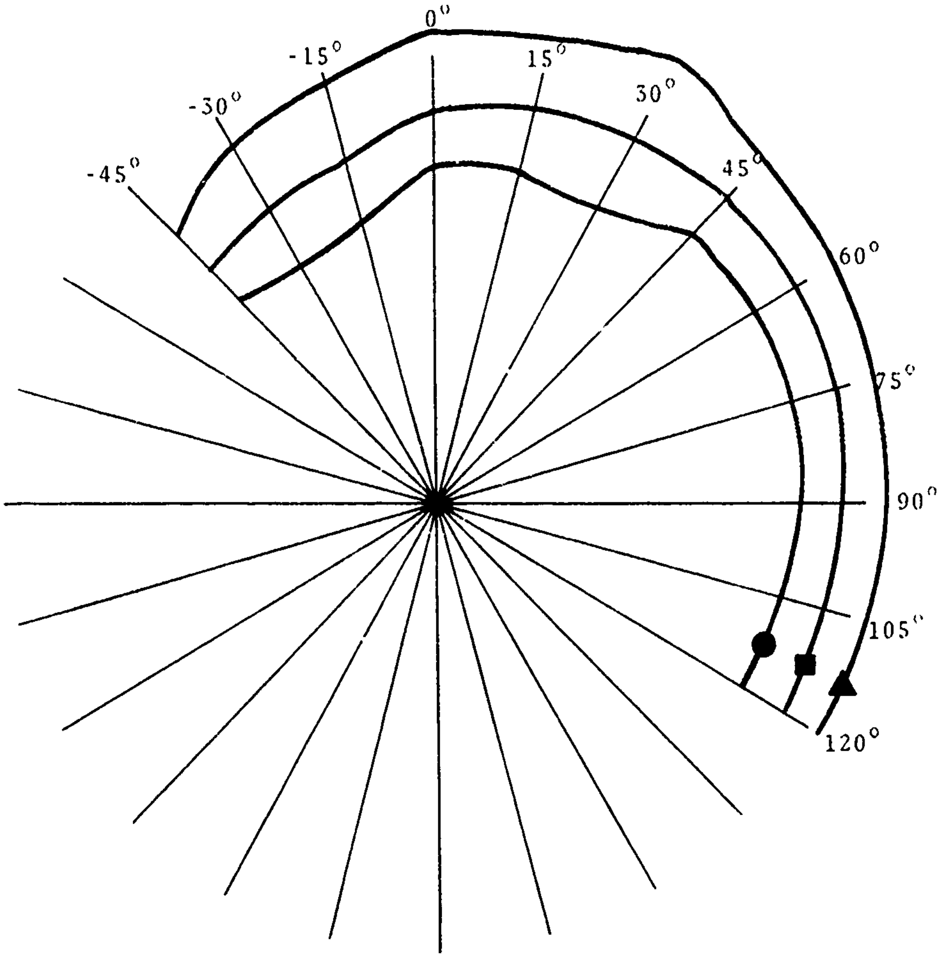
● 5th Percentile

■ 50th Percentile

▲ 95th Percentile

Figure 16. Reach Envelope for Unrestrained Females

40-cm Altitude

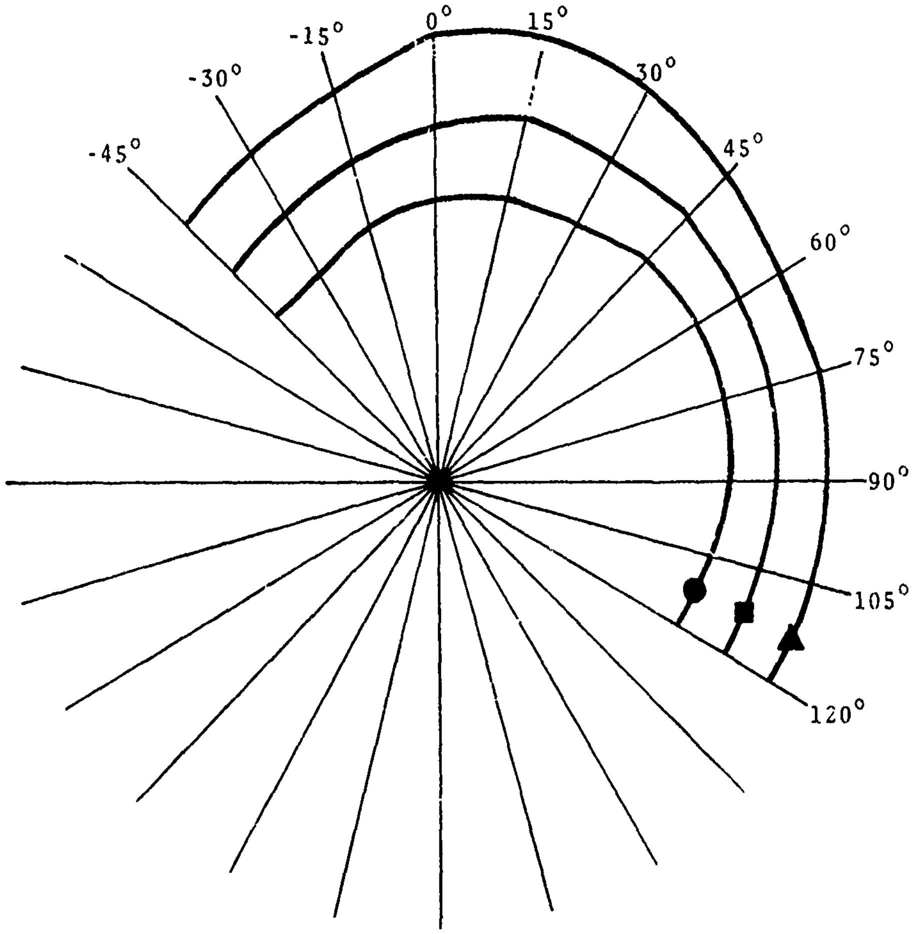


5th Percentile

50th Percentile

95th Percentile

Figure 17. Reach Envelope for Unrestrained Females 60-cm Altitude.



● 5th Percentile

■ 50th Percentile

▲ 95th Percentile

Figure 18. Reach Envelope for Unrestrained Females
90-cm Altitude.

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